

THE EFFECTIVENESS OF SCAFFOLDING TREATMENT ON COLLEGE
STUDENTS' EPISTEMOLOGICAL REASONING ABOUT HOW DATA ARE USED
AS EVIDENCE

A Dissertation

by

CHRISTINA MARIE SHIMEK

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2012

Major Subject: Educational Psychology

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Reasoning About How Data Are Used as Evidence

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Approved by:

Co-Chairs of Committee	Ernest T. Goetz Cathleen C. Loving
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ABSTRACT

The Effectiveness of Scaffolding Treatment on College Students' Epistemological

Reasoning About How Data Are Used as Evidence. (May 2012)

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College students rarely engage model-based epistemological reasoning about scientific data and evidence. The purpose of this study was to (1) investigate how scaffolding treatments influenced college students' epistemological reasoning about how data are used as evidence, (2) describe students' epistemological reasoning practice over the course of the study, (3) learn more about relationships among students' domain knowledge, epistemological beliefs about scientific knowledge, and epistemological reasoning, and (4) investigate how scaffolding for epistemological reasoning influences knowledge gain.

Participants in this study consisted of three-hundred fifteen undergraduate students; all were juniors and seniors and all students were enrolled in one of two introductory genetics laboratory courses. Study participants included non-majors (Experiment 1, N = 143) and majors (Experiment 2, N = 172).

A partially mixed-methods sequential research design was used in this study; qualitative and quantitative phases were mixed during data analysis. A distributed scaffolding system was used in this study. All participants from each laboratory section

were randomly assigned to one of three treatments; no scaffolds, domain-general scaffolds, or domain specific scaffolds. Study variables included domain knowledge, epistemological beliefs about the nature of scientific knowledge, and epistemological reasoning, scaffolding treatment was the manipulated variable.

Findings were: (1) Chi square analysis indicated no statistically significant differences in epistemological reasoning by scaffolding treatment; model-based reasoning was not observed in students' explanations; (2) Spearman rho indicated no change in epistemological reasoning over the course of the study, however, statistical significance was not reached, however, a repeated measures ANOVA with Greenhouse-Geisser correction indicated a statistically significant within subjects change in epistemological reasoning, implications are discussed; (3) statistically significant bivariate correlations were found and (4) ANCOVA indicated pretest domain knowledge was a statistically significant covariate for posttest domain knowledge and a statistically significant main effect for scaffolding treatment was reached by Experiment 1 participants but not by Experiment 2 participants. Implications for instructional design and future research are discussed.

DEDICATION

This one's for me! (Thanks for the music, TP!)

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CHAPTER 1

INTRODUCTION

Classroom science often promotes cookbook style laboratory activities; students from middle school to college perform laboratory activities, collect data, and consider the results valid when the data directly support a particular theory. When the data do not clearly support the desired theory, students often claim human error is the culprit; students recognize that systematic error has been committed and the explanation is accepted as a legitimate, sufficient reason for data that cannot be used as evidence.

Consider, for example, an acid-base titration experiment in which sodium hydroxide is used as the base. Most students simply use the concentration of sodium hydroxide identified on the container, and are baffled when an incorrect answer is obtained for the experimental results.

On one hand, students will often claim human error and will often identify simplistic systematic error arising from poor procedures or not following instructions (e.g., not reading volumes correctly, or not recognizing the experimental endpoint required for data collection). Using a conceptual model, on the other hand, scientists recognize that sodium hydroxide is very reactive with water and that water can be absorbed from atmospheric moisture. If atmospheric humidity is high and the sodium hydroxide solution is not fresh, the sodium hydroxide can absorb moisture from the air, essentially reducing the concentration of the base.

This dissertation follows the style of Journal of Research in Science Teaching.

Considering that students rarely use conceptual models to justify and explain how data can or cannot be used as evidence, there should be no surprise at the ubiquitously present research reports about how students of all ages cannot use scientific evidence to support scientific knowledge claims. One reason students have so much difficulty using evidence is that they may not adequately understand how to use conceptual models and theoretical frameworks to explain how data are used as evidence; if students are unable to distinguish data and evidence how can they correctly use evidence to support scientific knowledge claims?

Using scientific conceptual knowledge, and theories, etc. to explain how data are used as evidence plays an important role in scientific practice (Duschl, 2008). Scientists use logical reasoning grounded by conceptual models or theoretical frameworks to explain data patterns. Consequently, reasoning about and explaining how data are used as evidence are important activities worth doing in classroom science (Carey, Evans, Honda, Jay & Unger, 1989; Chinn & Malhotra, 2002; Driver, Leach, Millar & Scott, 1996).

A survey of the literature reveals an extensive number of studies about how students use evidence in scientific knowledge claims and explanations; yet, even when students generate explanations about evidence, students are rarely expected to use conceptual models in explanations about how data are used as evidence. Generating explanations about how data are used as evidence requires model-based reasoning. If students do not use conceptual models to distinguish data from evidence, how can we expect them to use evidence in knowledge claims?.

Reasoning

Reasoning is defined by Webster as; "the process of thinking about something in a logical way in order to form a conclusion or judgment" (Reasoning.). Humans are capable of reasoning from everyday experiences; however, everyday experiences can be often include informal thinking that results from exposure to phenomena as well as formal thinking about conceptual models and theoretical frameworks.

Reasoning from everyday experiences helps students establish explanation plausibility and prevents an individual from becoming overwhelmed from the “countless number of correlations in a complex world” (Zimmerman, 2000, p. 125). Strongly held individual beliefs (appropriate or not) often become warranted through the “trustworthiness of constant conjunction” (Dewey, 1991, p. 147) and lead to naive beliefs and misconceptions (e.g., correlation infers causation) that are tightly embraced by learners. In summary, when students rely upon naïve understandings about how the world works, simplified understandings can get in the way of good scientific reasoning about how data are used as evidence.

Peirce (1955) described everyday reasoning in context of scientists’ everyday professional experiences with data and evidence; scientists combine everyday experiences and formal training to think about data and evidence. Peirce argued that while scientists engage inductive reasoning to build theories, there is a “certain element of guesswork” (p. 152) from scientists’ beliefs and everyday experiences with data and theory and that this special case of induction requires abduction of experiential knowledge gained from doing science (e.g., everyday reasoning). The combination of

everyday professional experiences with systematic logical thinking is called abductive reasoning.

Furthermore, Peirce argued that beliefs should drive scientific discovery because all humans often use experience-based beliefs to explain everything in life; scientists use experimentation to test beliefs. Pierce was heavily invested in the thought that scientists use every day professional experiences with logical thinking and he argued that not testing beliefs “is immoral as it is disadvantageous” (p. 21). Students in science classrooms often establish scientific plausibility through everyday classroom science experiences, rather than every day professional scientific experiences, but students often use naïve logic about experimental results. Students' limited experiences with scientific knowledge often influences engagement of simplistic forms of reasoning during classroom science (Chinn & Malhotra, 2002). Furthermore, students are often unable to make sense of something novel that contradicts experiences. In other words, student explanations, justifications and knowledge claims are constrained by limited experiences with scientific thinking about data and evidence.

Scientific reasoning is a logical process that includes inductive logic for theory building and deductive logic for theory confirmation. Scientists spend a considerable amount time routinely thinking about data and evidence according to theories in a discipline; scientists use both inductive and deductive logic to ponder and justify scientific knowledge. For example, inductive logic was used to derive theories about planetary motion, gravity, atomic nuclear materials, as well as the discovery of the cause of mad cow disease. Deductive logic was used to investigate the usefulness of existing

planetary motion theories to describe the motion of newly discovered planetary bodies (Dunbar & Fugelsang, 2005), and the effectiveness of a medical breakthrough to treat mad cow disease.

Lawson (2005; 2010) completely discounts the validity of inductive logic for theory building; Lawson uses the Popperian notion that induction cannot truly exist because only theory falsification exists. Lawson does not completely discount deduction but, rather, contends that deduction is an incomplete form of reasoning that allows one to identify examples of a phenomenon, but does not allow one to explore non-examples of a phenomenon. Finally, Lawson argues that hypothetico-deductive reasoning is a complete form of reasoning that helps students successfully examine data to characterize the fit between the data and theory; students are more successful using hypothetico-deductive reasoning to identify the fit between data and theory as a way to justify the use of data as evidence in light of the theory.

Epistemological reasoning describes how scientists think about data and evidence as well as how students think about data and evidence (Chinn & Malhotra, 2002; Sandoval & Reiser, 2004; Sandoval & Millwood, 2005). The difference is that when thinking about data and evidence, scientists engage model-based reasoning and students rarely engage model-based reasoning. In other words, epistemological reasoning about science includes different levels of sophistication; scientists use more sophisticated logical thinking whereas students most often use less sophisticated logical reasoning to think about and describe data and evidence (Chinn & Malhotra, 2002); scientists' use model-based reasoning so model-based reasoning is the gold standard for sophisticated

epistemological reasoning in science. In order to qualify students' epistemological reasoning, an empirical coding framework is needed to link reasoning to assertions or explanations about data and evidence.

The Driver et al. (1996) framework links explanations with categories of epistemological reasoning. Three categories of epistemological reasoning in the framework are; (1) phenomenon-based reasoning, (2) relation-based reasoning, and (3) model-based reasoning. In phenomenon-based reasoning, the nature of explanation is descriptive, and there is no separation between the phenomenon and the explanation and the language of observation is used in the explanation. In relation-based reasoning, the nature of explanation includes an empirical generalization about variable relationships and correlation is perceived as causal. In other words, the language of explanation emerges as an empirical generalization or causal relationship from the data. In model-based reasoning, there is a discontinuity between observation and explanation. The explanation language explicitly describes the behavior of a phenomenon using detailed information included from a conceptual model or a theoretical framework.

The Driver et al. (1996) model provides a reasonable framework to evaluate students' epistemological reasoning from explanations about how data are used as evidence. Each category of epistemological reasoning framework is illustrated through form of scientific enquiry, nature of an explanation, and relationship between an explanation and a description; scientific enquiry form describes the purpose each epistemological reasoning level (See Figure 1). Phenomenon-based reasoning is illustrated as; a focus on the phenomenon, an explanation that is a description, and a lack

of clear distinction between an explanation and a description of a phenomenon. Relation-based reasoning is represented through; a focus on variable correlations, an explanation that illustrates an empirical generalization, and an inductive relationship between the explanation and the description of a phenomenon. Model-based reasoning is demonstrated by; a focus on theory evaluation, an explanation that illustrates features of modeling (e.g., a discontinuity between observation and theory), and a hypothetico-deductive relationship between an explanation and a description of a phenomenon.

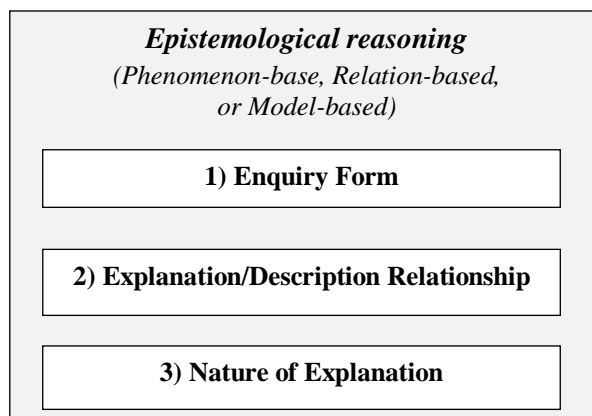


Figure 1. The Driver et al. (1996) framework for epistemological reasoning.

As members of a practicing community of scientists understand that acceptable conceptual models are used to justify the use of data as evidence, but when presenting scientific knowledge claims and evidence, scientists rarely include explicit details of

each conceptual model to peers. Students are not practicing members of the scientific community and often enter college level studies with the notion that data collection has the purpose of theory verification through simple deduction; as a consequence, students fail to recognize the important connections between conceptual models and justification of data as evidence. In order to help teachers and researchers more carefully examine student understanding of data and evidence, students must make their thinking visible through instructional products (e.g., explanations about how data are used as evidence) that can be characterized by an epistemological reasoning framework. Therefore, students must learn to use conceptual models to justify data to evidence transformations, rather than to simply believe that all data are suitable evidence for a scientific knowledge claim.

Variables Influencing Epistemological Reasoning

Two variables that influence epistemological reasoning are domain knowledge and epistemological beliefs about scientific knowledge. Scientists routinely rely upon vast reserves of domain knowledge and sophisticated epistemological beliefs about scientific knowledge to drive their epistemological reasoning about data and evidence. Students' domain knowledge and epistemological beliefs about scientific knowledge should be considered as variables in studies about epistemological reasoning about data and evidence.

Domain knowledge is the corpus of knowledge specific to a particular field of study (Alexander, Schallert, & Hare, 1991). Domain knowledge influences data interpretation (Klahr, Fay, & Dunbar, 1993; Passmore & Stewart, 2002; Sandoval, 2003;

Windschitl, Thompson, & Braaten 2008) and data to evidence explanations (Kelly & Takao, 2002; McNeill and Krajcik, 2007; Metz, 2000; Sandoval, 2003; Toulmin, 1958; 2003).

Two overarching categories of knowledge used by scientists are; (1) domain-general and (2) domain-specific. Domain-general knowledge is knowledge that can be used across all scientific disciplines; domain-general knowledge helps students use domain-specific knowledge in order to analyze phenomena (Penner, 2000). For example, when conducting experiments, all scientists employ experimental and control conditions, transform observations, and find flaws in data (e.g., Chinn & Malhotra, 2002). Domain-specific knowledge in science is knowledge used exclusively in certain disciplines. Domain-specific knowledge influences how individuals attend to features or patterns of a phenomenon (Alexander & Judy, 1988) and helps identify evidence (Passmore & Stewart, 2002). For example, all scientists use experimental controls, but different kinds of explicit controls and standards are used by an ecologist as compared to those used by a molecular biologist.

Epistemological beliefs about scientific knowledge constitute a second variable influencing epistemological reasoning (Ryder, Leach, and Driver, 1999; Grosslight, Unger, Jay, & Smith, 1991; Smith & Wenk 2006). In general, there is a direct relationship between sophisticated epistemological beliefs about scientific knowledge and model-based reasoning. For example, students who believe that scientific knowledge is subjective are more likely to recognize the need for conceptual models and theoretical frameworks to justify how data are used as evidence.

Professional consensus indicates that epistemological beliefs evolve over time and can be influenced by education level and major field of study (Buehl & Alexander, 2006; Davis, 2003b; Jeng, Johnson, & Anderson, 1993; Kitchener & King, 1981; Palmer & Marra, 2004); however, how to operationalize epistemological beliefs is debated in the literature. Some researchers indicate epistemological beliefs are decontextualized and generically applied in a stable manner (Hofer & Pintrich, 1997; Schommer, 1994); others argue that epistemological beliefs are context-based and drawn from extensive cognitive resources built from everyday experiences (Hammer, 1994; Elby & Hammer, 2001; Hammer & Elby, 2002).

As experts, scientists have more sophisticated epistemological beliefs about scientific knowledge than do students, and scientists recognize the need for experimental standards and controls to explain how data are used as evidence. Thus, one might suggest that a sophisticated epistemological belief about scientific knowledge is that scientific knowledge is tentative, but resilient, and that context does matter.

However, judging the sophistication of students' epistemological beliefs about scientific knowledge is not easy; sophistication consists of both productivity and correctness of the belief, and must be evaluated in the context of use (Elby & Hammer, 2001). For example, the notion that knowledge is tentative is neither correct nor productive when considering whether the earth is round or flat.

In this study, epistemological reasoning was situated in students' explanations (Driver et al., 1996) about how data are used as evidence. Epistemological beliefs about scientific knowledge shape one's explanations and arguments and, therefore, one's

epistemological reasoning (Sampson and Clark, 2006). While there is a plethora of literature to support the notion that epistemological beliefs about scientific knowledge drive explanation sophistication, there is little empirical evidence to support this notion (Sampson & Clark, 2006). Therefore, measuring students' epistemological beliefs about scientific knowledge and then examining the relationship between epistemological beliefs about scientific knowledge and epistemological reasoning about how data are used as evidence may yield greater understanding about more efficient instructional design to promote model-based reasoning.

Science Instruction and Epistemological Reasoning

The nature of science is concerned with values and epistemological assumptions underlying scientific knowledge building activities including data collection, data interpretation and drawing conclusions (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002) as well as model-based reasoning. Scientific knowledge is at the heart of science and evidence is critical for the defense of knowledge claims. Science instruction has not traditionally addressed model-based transformations of data to evidence (Duschl, 2008). Driver et al. (1996) stressed the critical role played by a theoretical underpinning for a model-based transformation of data to evidence;

Knowledge claims in science are supported or refuted in the light of available evidence. Therefore, some appreciation of the nature of empirical data and systematic ways of collecting it and evaluating its quality or trustworthiness will be a necessary underpinning to an understanding of scientific knowledge claims (p. 144).

Frequently, college students perform routine confirmatory style science laboratory activities (Windschitl, 2002) and are then expected to construct a meaningful evaluation of the resulting data. Helping students understand transitional practices and use model-based reasoning in laboratory science activities exemplifies the nature of scientific knowledge building practices (Chinn & Malhotra, 2002) and should be part of science instruction (Duschl, 2008; Sandoval & Reiser, 2004).

Unfortunately, students generally rarely model-based reasoning to explain how data are used as evidence (Driver et al., 1996), often rely upon personal interpretations of data (Hogan & Maglienti, 2001) or may simply not recognize the need to explain how data can be used as evidence because data appear to be self-explanatory by existence without the need for further explanation (Sandoval, 2003). One reason may be that even in classrooms where evidence explanation is practiced there is still little emphasis on explaining how data are used as evidence (Ruiz-Primo, Li, Tsai, & Schneider, 2008). Instructional learning support (scaffolding) can reduce complexity of the task at hand and help students accomplish the task by using model-based reasoning to explain how data are used as evidence.

Scaffolding

Scaffolding is an instructional metaphor that represents a "process through which individuals are supported in identifying, interpreting, or otherwise using resources" (Hannafin & Hill, 2008, p. 526). Resources include assets available for learning. In this study, resources included PowerPoint presentations, the laboratory manual, course textbook, lecture notes and laboratory recitation notes; the laboratory manual was the

primary resources used by students. Scaffolding reduces the complexity of a task (Quintana, Reiser, Davis, Krajcik, Fretz, Duncan, et al., 2004), supports thinking about advanced activities and helps students recognize salient features for the task at hand (Pea, 1985; 2004). Scaffolding helps students accomplish tasks that would be too difficult for them to accomplish on their own.

Scaffolds are the instructional components integrated with activities to help students accomplish tasks they may not accomplish on their own. Hannafin, Land, & Oliver (1999) identify four types of scaffolds (1) conceptual, (2) metacognitive, (3) procedural, and (4) strategic; each type of scaffold has a different function to guide and support learning efforts. Conceptual scaffolds guide students about what to consider when the problem task is defined. Metacognitive scaffolds guide students to think about potential strategies to consider and prompt students to evaluate progress, or to consider self-regulating milestones. Procedural scaffolds guide students to use available resources. Strategic scaffolds guide students to analyze and perform learning tasks.

The instructional scaffolding metaphor is grounded in Vygotsky's (1978) theory about the Zone of Proximal Development (ZPD). Vygotsky argued that human development occurs through socio-cultural interactions that take place when a less knowledgeable individual is supported with guidance from a more knowledgeable other. The ZPD integrates student development through a lower level defined by the ability of the student to independently solve problems, and an upper level defined by what the student can do with assistance from a more capable other (e.g., a tutor or more capable

peer). Ideally, students begin with assistance from others and that assistance fades over time as the student becomes more independent (Vygotsky, 1978).

Over the last 30 years, the more knowledgeable other has evolved from dynamic adaptable human delivered assistance to static, written instructional prompts designed to deliver assistance. Initially, the notion of scaffolding defined the more knowledgeable others either as adults engaged in adult-child dynamic interactions whereby the child learned from the adult (Wood, Bruner, and Ross, 1976). Palincsar & Brown (1984) defined the more knowledgeable other as a classroom teacher who first modeled cognitive activities for students, and then provided as needed adaptable assistance to help students become more proficient at a task. Peer interactions have also been defined through more knowledgeable and less knowledgeable participants; when more knowledgeable students provide as needed assistance to less knowledgeable students.

Scaffolding tools are another form of instructional learning support. Scaffolding tools can be technology-based, or paper-based. Computer-simulated experiments are scaffolding tools that allow students to explore models (White & Frederiksen, 1998) and to visualize complex data patterns (Chinn & Malhotra, 2002; Gordin & Pea, 1995; Hofstein & Lunetta, 2004); computer-simulated experiments provide scaffolding to reduce real world complexity and to make tasks more manageable (Pea, 1985; 2004; Quintana, et al., 2004). Computer-simulated experiments have been criticized because students explore only those variables included in the simulation (Chinn & Malhotra, 2002); However, limiting the variables to only those of interest can be useful to help students think about relevant experimental parameters (Lee, Guo, & Ho, 2008) and to

help students become familiar with a model. A design diary that includes pages with questions or prompts to help students identify and reflect about activities in order to learn from those activities is a paper-based scaffolding tool (Puntambekar & Kolodner, 2005); another example of a paper-based scaffolding tool is a laboratory manual with questions designed to help students think about and evaluate data and evidence.

The introduction of written prompts as scaffolds (White & Frederiksen, 1984), resulted in a nomenclature system to distinguish scaffolds based on dynamic versus static delivery; learning support provided through dynamic, adaptive interactions are called soft scaffolds and learning support provided through static, written instructional supports are called hard scaffolds (Saye & Brush, 2002). Soft scaffolds have an advantage over hard scaffolds because students receive information on an as needed basis, and retains Vygotsky's notion of fading over time for eventual student independence. Because there are often multiple ZPDs present in science classrooms, one instructor simply cannot accommodate all students with individualized, as needed soft scaffolds in the limited time frame of a class period (Stone, 1998; Tabak, 2004). Hard scaffolds provide a potentially promising solution for limited use of individualized soft scaffolds in large classrooms when multiple ZPDs are present (Puntambekar & Hubscher, 2005). Greater understanding about the use of hard scaffolds in classrooms, therefore, can potentially improve future instructional design for complex learning in complex environments.

The use of hard scaffolds to engage students' zones of proximal development has become more commonly used in education research (e.g., Bell & Linn, 2000; McNeill,

Lizotte, Krajcik, & Marx, 2006). This transition from scaffolds as dynamic, adaptable support provided by an adult, teacher, or more capable peer to scaffolds as static, written prompts has drawn criticism (Pea, 2004; Puntambekar & Hubscher, 2005) because scaffolds are more difficult to fade when the relationship is not dynamic especially since static scaffolding is not dynamically adapted to individual student ZPDs. On the other hand, we simply do not know what skills can be faded and if scaffolds for a complex skill are faded too quickly, students may not benefit from instructional support. The scaffolds used in this study were not faded due to the complex nature of model-based reasoning, but rather, two kinds of hard scaffolds were compared to each other and to a no scaffolds control group.

One way to enhance effectiveness of written prompts (hard scaffolds) is to use them as part of a distributed system. Distributed systems feature multiple scaffolding forms in rich, complex learning environments to facilitate development of one or more learning needs (Tabak, 2004). More efficient classroom-friendly scaffolding can be achieved through a distributed scaffolds model when multiple scaffolds are designed to interact to synergistically support a complex task (Tabak, 2004). For example, both hard scaffolds and soft scaffolds can be combined with multiple scaffolding tools to help students engage model-based reasoning about data and evidence.

Distributed systems may include scaffolding components for each of several learning needs or multiple scaffolding components for a single learning need. Multiple scaffolds that support a single learning need are redundant scaffolds that become synergistic when they act simultaneously to augment each other and “work in concert to

guide a single performance of a task or a goal” for a single learning need (Tabak, 2004, p.318); redundant scaffolding components interact and fit together like pieces of a puzzle.

Redundant, synergistic scaffolding components offer a potential solution to challenges posed by complex learning goals. For example, in order to explain how data are used as evidence, students must be able to; recognize ideal data patterns, explore how experimental parameters influence those ideal patterns, and use conceptual models or theoretical frameworks to make meaning of data and data patterns. Using conceptual models and theoretical frameworks to explain how data are used as evidence is a complex learning goal that is beyond most students' abilities without some form of guidance.

Although studies investigating kinds of scaffolds to support students' explanations about how data are used as evidence are visibly missing from the literature (Duschl, 2008; Ruiz-Primo et al., 2008), a considerable amount of research about how students explain the use of evidence to support knowledge claims has been generated (e.g., Bell & Davis, 2000; Bell & Linn, 2000; Clark & Sampson, 2007; Kelly, Drucker, & Chen, 1998; Jiménez-Aleixandre & Pereiro-Muñoz, 2002; Jiménez-Aleixandre, Rodríguez, & Duschl, 2000; Kelly & Takao, 2002; McNeill et al., 2006; Sandoval & Millwood, 2005; and Zohar & Nemet, 2002). The literature about how students explain and use evidence to support scientific claims helps provide a framework for scaffolding intended to support explanations about how data are used as evidence.

Statement of the Problem

Using model-based reasoning to justify data used as evidence to support a scientific knowledge claim is a critical component of scientists' work, yet, research indicates that college students often fail to use model-based reasoning in classroom science (Hartley, Wilke, Schramm, D'Avanzo, & Anderson, 2011). One reason may be that college students do not understand the critical role of conceptual models and theoretical frameworks to judge whether data can be used as evidence. Furthermore, even when students receive instruction in evidence explanation, there is little emphasis on transforming data to evidence (Ruiz-Primo et al., 2008). Previous research indicates that providing written prompts to help students draw links between a conceptual model and the task at hand offers promising results about students using model-based reasoning (Stephens, Campbell, McRobbie & Lucas, 1999).

Purpose of the Study

The purpose of this study was (1) to investigate how scaffolding treatments influence college students' epistemological reasoning about how data are used as evidence, (2) to describe students' epistemological reasoning practice over the course of the study, (3) to learn more about relationships among students' domain knowledge, epistemological beliefs about scientific knowledge, and epistemological reasoning, and (4) to investigate how scaffolding for epistemological reasoning influences knowledge gain.

Research Questions

Four Research Questions were addressed in this study:

- (1) Does scaffolding treatment influence epistemological reasoning?
- (2) Does epistemological reasoning improve with practice?
- (3) What are the relationships among content knowledge, epistemological beliefs about scientific knowledge, and epistemological reasoning?
- (4) Does scaffolding treatment influence domain knowledge gain?

Significance of the Study

This study has three potential implications for future instructional design of curricular materials aimed at facilitating model-based reasoning by college students. Model-based reasoning is difficult and rarely used by students (Driver et al., 1996; Hartley et al., 2011; Stephens et al., 2009). This study adds to existing knowledge about college students' epistemological reasoning categories engaged while performing laboratory activities, scaffolding treatment influences on college students' epistemological reasoning, and relationships among domain knowledge, epistemological beliefs about scientific knowledge, and epistemological reasoning. Research about the epistemological reasoning engaged by college students has been neglected and this study may help draw attention to the need for instructional scaffolding systems designed to support model-based reasoning in college science.

Definitions

Data are empirical representations that result from scientific experiments or methodologies; data are products of methodological commitments in a science domain (Duschl, 1990).

Domain-general knowledge is “broad, general knowledge of a formal field of study” (Shapiro, 2004, p. 163). Domain-general knowledge includes declarative and procedural knowledge that can be used across disciplines. For example, scientists use controls and standards to justify validity of data obtained from experiments.

Domain-general scaffolds are written prompts designed to help students think about scientific knowledge using domain-general knowledge. Domain-general scaffolds have also been described in the science education literature as generic scaffolds (Davis, 2003a; McNeill et al., 2006).

Domain-specific knowledge is “specialized knowledge that is more specific to a given text” (Shapiro, 2004, p. 163). Domain-specific knowledge includes declarative and procedural knowledge associated with a discipline. For example, when a scientist collects data from a Polymerase Chain Reaction (PCR) experiment, relevant controls and standards explicit to PCR experiments are used to characterize and justify validity of data obtained from PCR experiments.

Domain-specific scaffolds are written prompts designed to help students think about scientific knowledge using domain-specific knowledge. Domain-specific scaffolds have also been called direct (Davis, 2003a) or context specific scaffolds (McNeill et al., 2006) scaffolds.

Epistemological beliefs about scientific knowledge represent what counts as reliable scientific knowledge (Sampson & Clark, 2006). “The word ‘beliefs’ here does not refer to students’ conceptual understanding of science topics, but rather to their ideas about what science is like as a field, what counts as science, how one does science, and how one learns science” (Davis, 2003b, p. 440). Epistemological beliefs are often validated through everyday experiences about how the world works (Chinn & Malhotra, 2002) and to some degree, students are guided by the beliefs they hold about science and scientific data (Bell & Linn, 2000). A difficulty arises when students believe scientific data are self-explanatory (e.g., Sandoval & Millwood, 2005) and fail to recognize the need for model-based reasoning to explain how the data are used as evidence.

Epistemological reasoning describes how scientists think about data and evidence and how students think about data and evidence (Chinn & Malhotra, 2002; Sandoval & Reiser, 2004; Sandoval & Millwood, 2005); epistemological reasoning is grounded by the individual’s domain knowledge and by beliefs about scientific knowledge. Scientists use model-based reasoning whereas students use rarely use model-based epistemological reasoning to explain how data are used as evidence (Chinn & Malhotra, 2002; Driver et al., 1996).

Evidence consists of data that have been critically evaluated, judged, and transformed through a logical process using conceptual models or theoretical frameworks to explain why data are accepted or denied as evidence (Chinn & Brewer, 2001). While many studies in the science education literature ask students to use evidence to support a scientific knowledge claim (e.g., Ruiz-Primo et al., 2008;

Sandoval, 2003; Sandoval & Millwood, 2005), this study investigates students' epistemological reasoning illustrated by explanations of how data can be used as evidence.

Model-based reasoning is illustrated when an explanation no longer uses "the language of observation" (Driver et al., 1996, p. 116); in these explanations, the student clearly indicates knowledge about intricate details of conceptual models or theoretical frameworks. Explanations that represent model-based reasoning occur when there is a "discontinuity between observation and explanations" (p. 116); the language of the explanation describes "the behavior of the theoretical entities posited (whether molecules, electric fields or genetic code) within a theoretical system" (p. 116).

Phenomenon-based reasoning is illustrated when an "explanation is seen as a redescription of the phenomenon" (Driver et al., 1996, p.114). The explanation and the evidence (or data) are indistinguishable; the explanation presents a "taken-for-granted statement of how the world is" (p. 115). An example of phenomenon-based reasoning is when students assume that data are self-explanatory (Sandoval & Millwood, 2005) and need only be qualified in context of results; for example, the value of the data increase from the beginning to the end (inferring the reader understands and uses the necessary interpretive conceptual models or theoretical frameworks). In school science, students may assume that since the instructor already understands what the data mean, no explanation is necessary.

Relation-based reasoning is illustrated in explanations that include empirical generalizations as either correlations between the variables, or as "a chain of cause-and-

effect relationships or linear causal reasoning" (Driver et al., 1996, p. 115). For example, if a picture shows a balloon inflating with a temperature increase, one may write that as the heat inside a balloon increases, the size of the balloon increases. Explanations are written in the language of observation and lack reference to underlying mechanisms. In other words, the variable relationship describes behavior of the phenomenon.

Scaffolding is a metaphor that represents a "process through which individuals are supported in identifying, interpreting, or otherwise using resources" (Hannafin & Hill, 2008, p. 526). Scaffolding supports thinking about advanced activities and support recognizing salient features for the task at hand (Pea, 1985; 2004). Scaffolding helps students accomplish tasks that would be too difficult for them to accomplish on their own.

Scaffolds in this study were written prompts designed to help students identify conceptual knowledge to consider (Hannafin et al., 1999) and to support students' explanation construction (McNeill et al., 2006) about how data are used as evidence. Scaffolds can be delivered in soft or hard forms (Saye & Brush, 2002).

CHAPTER II

LITERATURE REVIEW

Reasoning is a thinking process; epistemological reasoning refers to the thinking process engaged by experts in a field. Three forms of epistemological reasoning are phenomenon-based reasoning, relation-based reasoning, and model-based reasoning (Driver et al., 1996). Model-based reasoning is the gold standard for epistemological reasoning in science because scientists engage model-based reasoning to justify how data are used as evidence. Using model-based reasoning to explain how data are used as evidence is critically important to generate evidence explanations linking data to scientific knowledge claims (Duschl, 2008). Unfortunately, even in classrooms where evidence explanation is practiced, there is still very little emphasis on transforming data to evidence (Ruiz-Primo et al., 2008). Following a discussion of research about epistemological reasoning and variables influencing epistemological reasoning, this chapter discusses key empirical studies about scaffolding students' explanations about how evidence supports scientific knowledge-based claims. Instructional scaffolds may provide a promising solution to help students engage model-based reasoning while generating explanations about how data are used as evidence.

Student Characteristics Influencing Epistemological Reasoning

Two student characteristics that influence epistemological reasoning in classroom science are domain knowledge (Hogan & Maglienti, 2001) and epistemological beliefs about scientific knowledge (Sampson & Clark, 2006). Scientists are experts in their fields and use vast reserves of domain knowledge to generate

scientific explanations about data and evidence (McNeill et al., 2006; Passmore & Stewart, 2002; Sandoval, 2003; Windschitl et al., 2008); scientists systematically reason about how data can be used as evidence in authentic science (Chinn & Brewer, 1993; Chinn & Brewer, 2001; Chinn & Malhotra, 2002). Research is needed to characterize relationships among domain knowledge, epistemological beliefs about scientific knowledge, and epistemological reasoning by science students.

Domain Knowledge

Students' existing domain knowledge (e.g., prior knowledge) substantially affects learning outcomes (Shapiro, 2004) including epistemological reasoning. For example, Hogan & Maglienti (2001) compared how eighth graders and science professionals judged hypothetical scientific conclusions about an ecosystem phenomenon. Participants were interviewed and explained why the conclusions were either valid or not valid. Results indicated participants unanimously relied upon prior domain knowledge to judge the scientific conclusions.

A tension exists about the kind of domain knowledge that needs to be stressed in order to enhance student thinking skills in science education, domain-specific knowledge or domain-general knowledge (Niaz, 1995). For example, Duncan (2007) argues that domain-specific knowledge is a key component essential for epistemological reasoning development and Lawson (2005; 2010) argues that domain-general knowledge is critical in student development of epistemological reasoning.

Domain-Specific Knowledge. Alexander & Judy (1988) found that students enrolled in the same course had similar domain-general knowledge; however, individual

differences in domain-specific knowledge significantly influenced domain-general learning outcomes. For example, students weak in relevant domain-specific knowledge often did not effectively use domain-general knowledge while engaged with complex tasks. As a consequence, the authors argued that sufficient domain-specific knowledge is a critical component that must be in place before a student is capable of using domain-general knowledge.

In a study about using molecular mechanisms to represent genetic phenomena, Duncan (2007) interviewed 10 undergraduate students enrolled in the second course of a three-course series required of all biology and pre-medical college majors; five interviews were conducted about students' conceptual understanding about genetic phenomena and molecular mechanisms. The researchers found that students used domain-specific knowledge forms to reason about both familiar and novel genetic phenomena.

Duncan argued that by teaching students to use domain-specific knowledge forms to think about genetic phenomena, detailed genetic mechanisms can be accurately identified and described by students. For example, the hint "genes-code-for-proteins" (Duncan, 2007, p. 293) helps students use appropriate language and terminology in explanations about the relationship between genes and proteins and how the genetic code influences protein structure.

Domain-General Knowledge. Lawson (2003; 2005) explicitly argued that the hypothetical deductive if/then/therefore pattern of reasoning is domain-general knowledge and domain-general knowledge is the limiting factor for scientific reasoning.

Lawson (2005) investigated how 667 undergraduates distinguished two hypotheses; the participants were enrolled in an introductory non-majors biology course. Study results indicated that when students used the if/then/therefore reasoning pattern to generate arguments supported by evidence, those students successfully excluded the alternative hypothesis and selected the appropriate hypothesis based on evidence. In other words, the undergraduates successfully used domain-general knowledge to link evidence and hypothesis. Lawson argued that students use domain-general knowledge in everyday reasoning in order to construct knowledge about that domain.

Epistemological Beliefs about Scientific Knowledge

Epistemological beliefs about scientific knowledge contribute to students' epistemological reasoning about data and evidence. Epistemological beliefs about scientific knowledge help distinguish data and evidence (Chinn & Malhotra, 2002) and facilitate understanding about the use of models in science (Bell & Linn, 2000; Driver et al., 1996; Grosslight et al., 1991; Havdala & Ashkenazi, 2007; Sampson & Clark, 2006; Tsai, 1999). Students' epistemological beliefs about scientific knowledge often differ substantially from scientists' beliefs (Grosslight et al., 1991); data may appear self-explanatory (Sandoval & Millwood, 2005) and require no explanation to support a scientific knowledge claim.

Tsai (1999) investigated how middle school students' scientific epistemological views influenced learning about science during laboratory activities. Students completed a questionnaire about scientific epistemological views and researchers observed students during a laboratory activity. Next, students were interviewed about responses to the

scientific epistemological-use questionnaire and about the laboratory observations.

Students with greater sophistication of epistemological views were more likely to spend additional time and effort interpreting or explaining data obtained during laboratory activities. Sophistication of epistemological beliefs about scientific knowledge directly influenced middle school students' model-based reasoning.

Havdala & Ashkenazi (2007) studied undergraduate students enrolled in a general chemistry course the first semester of their freshman year. Twenty-five participants conducted laboratory activities, and wrote laboratory reports. The final sample consisted of three students "whose views about science were very decisive and very different from one another" (p. 1139) were chosen for laboratory report analyses and interviews about theory and practice in science. The researchers used students' pre-lab and post-lab activities and conducted interviews about students' lab practices as data sources. Data analyses suggest students' epistemological beliefs influenced how the students engaged science laboratory practices and how students coordinated theory with empirical evidence.

Interview analysis indicated two participants believed that theory is tentative and that empirical evidence is gathered in order to give credibility to a theory. Laboratory report analyses for these two students indicated the first student believed experimental data are accurate, only if mathematical manipulations of the data supported the theory and attempted to reconcile conflicts by deductive application of theory and consideration of systematic. For example, failure of the data to support the theory was due to "inaccuracy of the students who performed the experiment, like inaccuracy in reading

the scale, inaccuracy in measurements, etc." (Havdala & Ashkenazi, 2007, p. 1150). In other words, systematic was responsible any time the data failed to verify the theory. The student also believed that the experimental objective should represent theory verification by empirical evidence obtained during the laboratory activity.

The second student also believed that systematic error is most often responsible for a conflict between data and theory and often made no attempt to reconcile conflict between data and theory. For example, if experimental protocol is followed exactly and if the answer is "different by orders of magnitude, you know for sure that you screwed up" (Havdala & Ashkenazi, 2007, p. 1151). When considering the experimental objective, the second student copied the wording exactly from the laboratory manual without any claims about the quality of the objective.

The third student believed that the relationship between data and theory depends on whether one starts with a theory and seeks evidence to support it, or has evidence and seeks a relevant theory. This third student always attempted to reconcile conflict between data and theory, applied the ideal theory, and considered limitations in context of experimental methodology. Laboratory report data indicated the third student also believed that a conflict between theory and empirical evidence was due to systematic error. For example, "there were small inaccuracies in the measurements" (Havdala & Ashkenazi, 2007, p. 1151). The student expressed the experimental objective according to limitations of the theory used during the laboratory activity.

Students' epistemological beliefs about scientific knowledge influence whether or not model-based reasoning is engaged during laboratory activities. Sophisticated

epistemological beliefs about scientific knowledge as tentative are associated with spending more time and effort interpreting or explaining data (Tsai, 1999), providing more model-based explanations (Bell & Linn, 2000), and resulting in strategies for the coordination of theory and evidence (Havdala & Ashkenazi, 2007). Unfortunately, results indicated that college students considered that the coordination of theory and evidence meant that all data collected during laboratory activities essentially served the purpose of theory verification. Using conceptual models and theoretical frameworks to explain how data are used as evidence is necessary for engaging model-based reasoning and should be integrated with science instruction (Duschl, 2008).

Epistemological Reasoning

Communities of practice (Wenger, 1998) establish community-accepted standards for epistemological reasoning within a domain; standards are developed through prior domain knowledge, as well as everyday professional experiences. Representations of students' epistemological reasoning in classroom science are based on the student's everyday experiences, knowledge about science, and beliefs about scientific knowledge (Driver et al., 1996). Students' everyday experiences are different from scientists everyday experience in what Chinn & Malhotra (2002) elegantly describe as “*antithetical* [italics added by author] to the epistemology of authentic science” (p. 175).

Early studies investigating model-based reasoning indicate that students are less likely to use model-based reasoning and more likely to use simpler forms of epistemological reasoning to think about scientific phenomena. For example, Driver et

al., (1996) interviewed students aged 9 to 16 years old about scientific phenomena in pictorial representations of experimental results. Students explained a scientific phenomenon represented by a picture of a series of glass bottles with a balloon over the neck of each bottle to illustrate how the balloon shape would change if the bottle were heated (thermal expansion) or cooled (thermal contraction). From the interviews, model-based reasoning was observed among only the 16 year old students, but the occurrence was rare. Most students engaged either phenomenon-based or relation-based reasoning.

In another study with middle school and high school students, Grosslight et al. (1991) interviewed 33 seventh graders and 22 11th graders, and then compared student responses to responses to those of four experts interviewed about models and the usefulness of models to explain scientific phenomena. All experts agreed that models were used as aids for understanding phenomena. Among the students, 3% of seventh graders and 14% of 11th graders mentioned models could be useful in explaining how something works. Overall, the 11th graders were more likely than the seventh graders to express responses with greater levels of sophistication; however, 11th graders fell significantly short from the level of expert.

While other researchers (e.g., Ryder et al., 1999; Smith & Wenk, 2006) interviewed students about representations of scientists' activities (e.g., interpreting data and evidence) and then used frameworks to analyze interview transcripts about students' abilities, understandings, and epistemological beliefs engaged, students in the Grosslight et al. (1991) study answered clinical questions about abstract scientific models not contextualized through concrete examples. In other words, students' abilities,

understandings, and epistemological beliefs were obtained directly from how questions were answered, rather than inferred from processes engaged by students. As a consequence, students' abilities, understandings, and epistemological beliefs were most likely underestimated, especially when considered against abilities, understandings, and epistemological beliefs of experienced scientists. Examples of questions asked during the interviews were: "What are models for? Can you use models in science? Would a scientist ever change a model?" (Grosslight et al., 1991, p. 803).

Ryder & Leach (2000) asked 731 high school and university students to complete a written survey about experimental data interpretation. Following completion of the survey, 19 of the participants in secondary science were also interviewed and results were used for the study. The survey asked students to give a brief description about how graphed data were interpreted by scientists. Next, students were instructed to consider how the data was analyzed and interpreted and to include that information in each student response to the survey. More than half of the student responses to the survey indicated that the use of models and data interpretation was either inappropriate or that the student was unsure whether or not the use of models was appropriate. When interviewed, 10 of the 19 students selected a model-based response as appropriate, but, seven of those 10 did not appear to understand why models were used to interpret data. Understanding and articulating model-based reasoning are difficult tasks for students, especially without instructional support.

Ryder et al. (1999) interviewed eleven students about how scientists do experiments and how scientists select appropriate research questions for scientific

experiments; the students represented five science departments. Each student was interviewed twice over the course of the semester; all students were enrolled in the final year of an undergraduate research project. Generic interview questions were posed to students. For example, "why do scientists do experiments?" (p. 204), and "how can good scientific work be distinguished from bad scientific work?" (p. 205).

The researchers found that the undergraduates primarily relied upon simple reasoning forms; students did not engage model-based reasoning to explain the relationships between scientific knowledge claims and data. Ten students expressed that knowledge claims can be proven by empirical evidence; five of the ten students claimed that meticulously following experimental procedures provided high reliability and validity for experimental results. Five other students claimed that selection of an experiment methodology provided results with the best reliability and validity and the last student claimed the same thing without any elaboration.

Ryder et al. (1999) did not interview scientists who mentored the students as a comparison to student results, however, the authors argued that "as mediators of the cultures of science, science teachers at all levels in the educational system need to make explicit to the images of science communicated through existing curriculum activities and those additional images they wish to incorporate in new curriculum developments" (p. 217). During the practice of science, in other words, scientists may not make explicit their use of model-based reasoning simply because they may assume that others, including students, have the same understandings.

Smith & Wenk (2006) investigated undergraduates' categories of reasoning about specific scientific controversies. Thirty-five college freshmen were interviewed and model-based reasoning was virtually nonexistent among the undergraduates. Most students explained that controversies were due to the use of different methods with different specific variables affecting the results. Very few undergraduates recognized that scientists' interpretation of results may not have taken into account alternate models to explain rival interpretations.

Overall, students expressed that controversies could be resolved using fewer variables or similar methods, and students rarely considered the need to use model-based reasoning to consider possible causal mechanisms. While previous studies classified epistemological reasoning into three categories, the Smith and Wenk study introduced the notion that intermediate levels of sophistication should be considered for undergraduate students.

Interview data indicate epistemological reasoning becomes more sophisticated with age, with science experiences (Driver et al., 1996; Grosslight et al., 1991), and with education level and major field of study (Palmer & Marra, 2004). Epistemological reasoning engaged by students of all ages is often simple (Driver et al., 1996; Ryder & Leach, 1999; Smith & Wenk, 2006), even when students participated in undergraduate research projects mentored by scientists (Ryder et al., 1999).

Each of the previous studies about epistemological reasoning used structured interviews to gather evidence of epistemological reasoning categories from middle school, high school, and college students. The greatest limitation for using structured

interview data about epistemological reasoning is that students may use tacit knowledge and be unable to adequately articulate an understanding about model-based reasoning (Ryder et al., 1999). Another limitation is that students are not actively engaged in the process of doing science.

Learning about the practices of a community (e.g., using models to interpret scientific data and explain how the data can be used as evidence) should be contextualized or situated in practice (Brown, Collins & Duguid, 1989). Two examples of situated learning instruction designed for improved use of model-based reasoning during science activities were found; one study with middle school students and one study with high school students.

In the first example, Petrosino, Lehrer, and Schauble (2003) provided middle school students with instructional support about using statistical distributions to analyze observed height of flight data collected from toy rockets launched as part of an eight-week study. Students initially believed that rockets with pointed cones would travel higher than rockets with rounded cones, so the researchers arranged for students to design and test the influence of nose cone shape on rocket height achieved. After students repeatedly measured how high rockets traveled with each type of cone, and then compared answers generated by all groups of students, the concepts of systematic and random errors became more apparent; students examined data and inferred that the rockets with round cones traveled higher than the rockets with pointed cones. Students next interpreted other data sets (e.g., measuring tree height for a sample of trees growing 3 months in light or dark soil) using statistical distributions to qualify the experimentally

collected data. Students engaged model-based reasoning and interpreted data according to a statistical model

In the second example, Stephens et al., (1999) provided instruction about electrical conductivity to twenty-six 10th-grade science students in an all-girls school. Student data collection occurred in three phases. In phase I, the students completed a paper activity and explained how six variables influenced electrical resistance. In phase II, students carried out laboratory activities, explored how the variables influenced electrical conductivity in wires and revisited explanations about electrical resistance from phase I. In phase III, the teacher lectured about how the electron drift model helped explain laboratory observations about electrical resistance and conductivity in metal wires. Next, students were provided a graphic representation of the electron drift model with written explanations corresponding features. Students were asked to draw picture representations that explained various electrical phenomena observed from laboratory experiments with wires and electricity. From phase I to phase III, the frequency of students' model-based reasoning statements increased in frequency.

Stephens, et al. (1999) coded student explanations with a modified version of the Driver et al. (1996) framework; model-based reasoning was divided into lower order and higher order versions. Lower order model-based reasoning included elements of relation-based reasoning and higher order model-based reasoning included explanations with greater model appropriate language, and without description of an empirical generalization (e.g. relation-based reasoning). The highest frequency of phenomenon-based reasoning statements was found in phases I and II. A sharp decrease in

phenomenon-based reasoning statements occurred in phase III and an increased frequency of model-based reasoning statements were observed over the course from phase I to phase III. Unfortunately, there were only 12 higher order model-based reasoning statements observed out of nearly 1000 student statements.

Overall results from the Stephens et al. (1999) study indicated that two elements of instructional design increased the frequency of model-based reasoning during laboratory activities; the use of graphics-based instructional materials with integrated written explanations about features of a phenomenon and the use of repeated exposure to the phenomenon. Furthermore, students failed to include model-based knowledge without prompts to consider the links between the model and the target (e.g., experimental data).

Using model-based reasoning is difficult for students of all ages; however, research indicates that appropriate instructional design helps students engage higher order reasoning about scientific knowledge. Outside the context of doing science, students have difficulty linking evidence and knowledge claims using conceptual models and theoretical frameworks. In the context of doing science, however, model-based reasoning can be facilitated by repeated practice with guidance from instructors or instructional materials. Research about scaffolding students' explanations about evidence-based scientific knowledge claims holds some promise for model-based reasoning engagement by students. Key research studies about scaffolding explanations about evidence-based scientific knowledge claims are presented in the remainder of this review.

Research About Scaffolds to Support Scientific Explanation

Scaffolds can help support middle school students' scientific explanations in (e.g. Bell & Davis, 2000; Bell & Linn, 2000; Clark & Sampson, 2007; Davis, 2003a; McNeill et al., 2006), high school science (e.g. Sandoval, 2003; Sandoval & Millwood, 2005; Sandoval & Reiser, 2004), and in college science (e.g., Kelly and Takao, 2002; Land & Zembal-Saul). Each of these studies about scaffolding scientific explanations provided distributed scaffolds for students engaged with one or more tasks; and each study suggested that both domain knowledge and epistemological beliefs influence the development of scientific explanations for evidence-based claims.

A review of the science education literature about scaffolding students' scientific explanations revealed three scaffolding characteristics; 1) delivery form of scaffolding support (hard scaffolds and soft scaffolds), 2) classification of knowledge included in the scaffolding (domain-general or domain-specific), and 3) the use of multiple redundant scaffolds and scaffolding tools to support complex learning goals. Each of the key research articles was categorized by scaffolding characteristics, domain knowledge, epistemological beliefs about scientific knowledge, and epistemological reasoning (see Table 1).

Table 1
Scaffolding features for research about scaffolding scientific explanations

	Study	Scaffolding Characteristics	Learner Knowledge	Epistemological beliefs	Epistemological Reasoning	Conclusions
Middle School Science	Bell & Linn (2000)	Free choice selectable scaffolding tools after hands-on data collection experiments; SenseMaker – organizational tool Mildred – note taking and guidance (DG and DS selectable hard scaffolds embedded) all participants received same treatment Soft scaffolds – teacher-led classroom discussions	normative understanding pretest/posttest	dynamic versus static and memorization versus understanding	Explanation structure and knowledge integration	<ul style="list-style-type: none"> • Dynamic beliefs correlated with use of multiple conceptual frames in explanations • Greater use of scaffolding hints associated with scientifically normative explanations • Significant learner knowledge improvement for all learners
	Clark & Sampson (2007)	Distributed Scaffolding Tools: Computer-assisted data collection/visualization and WISE interface with DG and DS hard scaffolds Soft – asynchronous threaded student-student discussions	Normative statements in explanations	Not measured	Explanation structure; epistemic value in rebuttals and counter-claims	<ul style="list-style-type: none"> • Limited number of normative science statements (appropriate principles, content) even when explanation structure ranked high
	Davis (2003a, 2003b)	Distributed scaffolding tools (see Bell & Linn, 2000; note, argument editor and discussion tool disabled) Hard - DG versus DS Reflection prompts in Mildred Soft -- not specified	Normative statements in explanations	autonomy, strategy, tentativeness	Explanation structure and knowledge integration	<ul style="list-style-type: none"> • DG prompts associated with more principles and normative statements than DS prompts condition • DG prompts most beneficial for high autonomy beliefs • tentativeness and strategy, significant positive correlation • autonomy and normative statements, significant positive correlation
	Davis & Linn, 2000	Distributed scaffolding tools (see Bell & Linn, 2000) Hard - Compared activity prompts to reflection prompts Soft -- not specified	normative statements (coherence)	beliefs prompts used with control groups	Decide how each piece of evidence helps/doesn't help the claim.	<ul style="list-style-type: none"> • Activity prompts, learners complete activities • Self-monitoring prompts elicit principles-based explanations with mixed results for conceptual quality (normative statements). • belief prompts group completed assignments similar rate to self-monitoring group

Table 1, <i>Continued</i>						
	Study	Scaffolding Characteristics	Learner Knowledge	Epistemological beliefs	Epistemological Reasoning	Conclusions
High School Science	McNeill, Lizotte, Krajcik & Marx (2006)	Distributed scaffolding tools: Project notebook (cumulative workbook with hard scaffolds for claim, evidence, reasoning) Hard (paper) - DS continuous compared to DS faded to DG Soft - teacher-led discussions (claim, evidence, reasoning)	pretest / posttest multiple choice and open-ended items content quiz	Not measured	evidence and claim linked with sufficient and appropriate content principles	<ul style="list-style-type: none"> • Limit statistical significance of results • Content knowledge did not explain reasoning differences between scaffolding groups • Higher reasoning scores in faded condition appears dependent upon understanding both content knowledge and scientific explanation • Content knowledge associated with explanation quality
	Sandoval, 2003	Distributed Scaffolding Tools (see Sandoval & Reiser, 2003) Hard - DS prompts (in explanation guide) Soft – whole-class discussions	causal coherence; Data reasonable with claim	Not measured	Causal coherence and evidentiary support (clear causal language)	<ul style="list-style-type: none"> • Students coherently used content knowledge and principles in explanation justifications (appropriate for context)
	Sandoval & Millwood, 2005	Distributed Scaffolding Tools (see Sandoval & Reiser, 2003) Hard - DS prompts (in explanation guide) Soft -- not specified	Causal coherence; Data reasonable with claim	Not measured	Sufficiency of cited evidence, rhetorical references	<ul style="list-style-type: none"> • Participants more likely to simply refer to data without explaining how the data are used as evidence
	Sandoval & Reiser, 2003	Distributed Scaffolding Tools: ExplanationConstructor with selectable tools; explanation guide, explanation notes, and evidence tool Hard -- DS prompts (explanation guide) Soft – whole-class discussions after students' used software	DS framework articulation	Not measured, Epistemic practices inferred	Causal coherence and evidentiary support (clear causal language)	<ul style="list-style-type: none"> • Participants discussed data interpretation, but rarely explained how data support claims • Participants recognized important data but did not always use it as evidence

Table 1, <i>Continued</i>						
	Study	Scaffolding Characteristics	Learner Knowledge	Epistemological beliefs	Epistemological Reasoning	Conclusions
College Science	Kelly & Takao (2002)	Distributed scaffolding tools: instructor lead discussions (lab and lecture), laboratory manual, and CD-ROM disk with extensive data sets. Hard – DS (laboratory manual) about scientific writing style Soft –DG scaffolds about scientific writing (lecture professor and laboratory instructors). Note: term “scaffolding” not used in this study	Normative statements in explanations	Not measured	Six epistemic levels for coding explanations (evidentiary support for plate tectonics theory)	<ul style="list-style-type: none"> Theories were more frequently linked to data through inferential statements rather than simple observation statements No clear relationship between coded epistemic level and scores from instructor-generated rubric (inconclusive)
	Land and Zembal-Saul (2003)	Distributed scaffolding Tool (Progress Portfolio) with experiment pages, and explanation pages Hard – DG prompts guide data interpretation (Explanation pages) Soft -- peer review for explanation revision	Three open-ended response questions about light phenomena.	Not measured	Explanation revision over time	<ul style="list-style-type: none"> Participants generated simple, observation-driven explanations and maintained those perspectives after prompted to reconsider Prior knowledge related to successful use of scaffolds
	Zembal-Saul, Munford, Crawford, Friedrichsen &, Land (2003)	Distributed Scaffolding Tools (see Sandoval & Reiser, 2003) Hard - DS prompts (in explanation guide) Soft -- not specified	Normative statements in explanations	Not measured	Causal coherence and evidentiary support (clear causal language)	<ul style="list-style-type: none"> All participants linked evidence to claims; however, evidence quality was seldom discussed

Middle-School Science

Six middle school studies used scaffolds that facilitated students' evidence-based explanations; five of the studies used technology-based scaffolding tools, and one study used paper-based scaffolding tools. The Knowledge Integration Framework project (Linn, 1995; Linn & Hsi, 2000) produced a series of studies by Bell & Linn (2000), Davis (2003a; 2003b), and Davis & Linn (2000). Two other studies did not use the knowledge integration environment; Sampson & Clark (2007) used technology-based scaffolding tools with hands-on data exploration, while McNeill et al. (2006) used a paper-based scaffolding tool with hands-on data exploration.

The knowledge integration environment is a web-based software application that allowed students to read about scientific phenomena, interpret evidence, and build arguments/explanations linking evidence to knowledge claims. Students first collected data from hands-on experiments and then used the knowledge integration environment for data sense-making and explanation construction. Two scaffolding tools included with the knowledge integration environment were SenseMaker and Mildred.

The SenseMaker scaffolding tool allowed students to select theories, to survey evidence, to build arguments/explanations and to plan a debate about the scientific phenomena. Students selectively viewed scientific arguments that modeled expert thinking or constructed new explanations for the topic. Additionally, SenseMaker allowed for collaboration, feedback and discussion among groups of students.

Mildred is a selectable scaffolding tool embedded within the knowledge integration environment interface. Mildred contains hints and guidance to help students

think about evidence and claims, and has space for students to type notes on the same screen with the written scaffolds. Student autonomy and reflection was supported through Mildred's guidance and students requested hints about the evidence for the activity.

Bell & Linn (2000) used the knowledge integration environment to facilitate middle school students' explanations about how evidence supports a claim. Students' beliefs about the scientific process were categorized as either process beliefs or strategy beliefs. Process beliefs about science were either dynamic (high sophistication belief) or static (low sophistication belief). Strategy beliefs about learning were either understanding (high level) or memorizing (low level). Process beliefs had a significant direct relationship with explanation quality. Strategy beliefs had a significant direct relationship with the use of multiple conceptual frames in student explanations. Student beliefs in understanding had a greater direct relationship than memorizing had to conceptual understanding.

Next, Davis & Linn (2000) provided middle school students with either activity prompts or self-monitoring prompts; students first designed clothing and shelter for aliens with different climate requirements and then critiqued evidence in a researcher-generated article about energy and thermodynamics. Activity prompts helped students complete specific aspects of the activity; self-monitoring prompts helped students plan and reflect. Results indicated that activity prompts help students to complete activities while reflection prompts provided mixed results. Furthermore, the reflection prompts

were somewhat effective, but only when students did more than just the minimum amount of work required.

The mixed results for the activity prompts in the Davis & Linn (2000) study were investigated further when Davis (2003a) used reflection prompts embedded in the knowledge integration environment were either domain-general scaffolds or domain-specific scaffolds. A design experiment methodology was used with comparison groups and no control group. Students in the domain-general scaffolding treatment were more likely to coherently use multiple domain principles in explanations linking evidence to a claim, and students in the domain-specific treatment were more likely to complete tasks in a piecemeal fashion with little evidence of knowledge integration in explanations.

Epistemological beliefs about science were measured by Davis (2003a) study and reported by Davis (2003b). Students' epistemological beliefs about science and science learning were measured along three dimensions; tentativeness of scientific knowledge (science as evolving or science as fixed), autonomous beliefs about science learning (responsibility for learning depends on self or responsibility for learning depends on the other) and strategy in science learning (try to memorize or try to understand). Generic prompts benefitted students with high autonomy beliefs about learning science the most.

Relationships for belief dimensions and conceptual quality were reported by Davis (2003b). The tentativeness and strategy dimensions had a significant positive correlation; no other significant correlations were reported. Conceptual quality had a significant positive correlation with autonomy, but did not have a significant relationship

with either strategy or tentativeness. The relationship between conceptual quality and scaffolding treatment was not reported in either study.

In the Clark and Sampson (2007) study, middle school students used computer-assisted data (e.g., computer-generated graphs prepared hands-on experimental data) to determine the temperature of objects in the classroom. Next, principles related to students' understanding about thermal equilibrium were constructed. Domain-specific scaffolds were provided using a principle-builder interface with drop-down selectable menus. Explanation quality was based on argumentation structure; rebuttals and counterclaims indicated higher explanation quality. Participants were equally likely to generate rebuttals as to not generate rebuttals. Normative conceptual content was rarely included in the students' evidence-based explanations.

McNeill et al. (2006) investigated the influence of fading domain-specific scaffolds on students' scientific explanation construction. Three hundred and thirty-one middle school students performed hands-on experiments and then generated explanations for a project-based chemistry unit. Domain-specific scaffolds were used in the constant scaffolding treatment and domain-specific scaffolds were replaced over time by domain-general scaffolding in the faded scaffolding treatment. The study took place over 36 class periods and students participated in 13 different activities.

The researchers scored students' explanations using a base rubric with three score levels; 0, 1, and 2. A score of zero indicated no reasoning or reasoning that does not link the claim to evidence, and a score of two indicated the use of sufficient and appropriate scientific principles (e.g., model-based reasoning). Data were analyzed at six

time points over the course of the study with similar mean score patterns generated for both groups about claim, evidence, and reasoning. There was a significant main effect for time, but not for scaffolding treatment. The mean posttest reasoning score was statistically significant for the topic that was more concrete (substance/property phenomenon) but not for the more abstract (chemical reactions) topic.

Four of the middle school studies were part of the knowledge integration environment collaboration aimed at learning more about how different kinds of scaffolds influenced students' evidence-based explanations. Davis & Linn (2000) anticipated that "belief prompts were unlikely to influence students' work on the rest of the project" (p. 826); belief prompts were provided for the control group.

The Sampson & Clark (2007) study was a pilot that investigated how students used menu driven prompts to generate explanations; all students received the same scaffolding treatment. This study was designed similar to the previous four studies with the exception that students' counter arguments and explanations were considered as higher-quality explanations.

The McNeill et al. (2006) study was a longitudinal study that investigated the influence of fading scaffolds. Scaffolding treatment did not produce a statistically significant main effect but time was statistically significant, and results indicated that the faded scaffolds provided an advantage for students when the topic was concrete but not when the topic was abstract. The researchers suggested that students had greater prior knowledge about the more concrete topic (substance/property) than the more abstract topic (chemical reactions); prior knowledge helped learners use scaffolds when the topic

is concrete. It seems reasonable, however, that asking middle school students to use chemical reactions to explain mass changes after dissolving Alka-Seltzer® in water may have been too abstract and too difficult for students either with or without scaffolds.

High School Science

Three high school studies used hard scaffolds to facilitate evidence-based explanations. Each study was part of the BGuILE (Biology Guided Inquiry Learning Environment) project, and each study provided domain-specific hard scaffolds embedded in the technology-based scaffolding tool (ExplanationConstructor). Scaffolds helped students use a given theory as a framework to explain data sets (Reiser, Tabak, Sandoval, Smith, Steinmuller, & Leone, 2001).

Sandoval and Reiser (2003) investigated how high school students used ExplanationConstructor scaffolding tools in the BGuILE software-based curriculum unit about natural selection. The students were enrolled in one of three biology classes taught by the same teacher. At the beginning of the study, the teacher taught about the theory of natural selection and discussed components of a good explanation (linking evidence and claims using explanatory frameworks).

The first year of the study examined how students explored and used ExplanationConstructor to build explanations. Selectable domain-specific scaffolds embedded within the explanation guides helped students generate explanations linking evidence to scientific knowledge claims. Students often explored data and recognized the importance of the explored data, but rarely used all important data to support claims. Furthermore, students often discussed data interpretation but rarely discussed ways to

use data to support their explanations. The researchers updated ExplanationConstructor interface with potential evidence immediately visible in the same screen. Further testing indicated students became increasingly aware of important data to include as support for a scientific knowledge claim.

Sandoval (2003) examined conceptual understanding illustrated in students explanations that used causal coherence--whether or not the explanations were normative. In other words, Sandoval was interested in learning more about whether or not students used pieces of data that fit within explanation despite the language used in the explanation. Appropriate causal language included clear causal language connecting data and claim (e.g., because, caused, due to, etc.). Causal "coherence was measured as a ratio of appropriate propositions in the Central causal chain to the total number of propositions in the network, resulting in a score from 0 to 1" (Sandoval, 2003, p. 26) and data were deemed appropriate if the data fit the context of use. For example, if students noted that surviving birds weighed more than birds that died, weight could be used as a differential trait even though it is not generally a normative practice to do so. Students were not expected to cite a sufficient amount of data to support the claim, but rather, were expected to demonstrate if the data could be reasonably related to the claim. Furthermore, Sandoval identified one limitation in the scaffolding tool; the explanation prompts did not support problems arising from data interpretations, especially when data are complex. The authors argued that students appeared to understand the need "to articulate causal mechanisms to explain data" (p. 41), however, student difficulty arose because "the data themselves were complex and hard to explain" (p. 41).

Finally, Sandoval and Millwood (2005) examined conceptual quality through students' theory-based explanations; conceptual quality was based upon data sufficiency and rhetorical reference. Data sufficiency was scored according to four components of natural selection theory, 1) environmental pressure, 2) individual effect, 3) differential trait, and 4) selective advantage. Students' sufficiency scores were summed from all four components. There were four levels of sufficiency ranging from 0 to 3 for each component; zero indicated no relevant data and three indicated all relevant data for each component of natural selection theory. Rhetorical references to data were categorized as, inclusion, pointer, description, assertion, or interpretation. Inclusion (lowest level) indicated that the inscription (data representation) was present but it was not referred to in the explanation, and interpretation (highest level) meant features of the inscription were explicitly defined in relation to a specific claim.

Conceptual quality was judged as reasonable given the data rather than as normative statements (see Sandoval, 2003 for an example). Data sufficiency and rhetorical reference categories were the primary data pieces. Results indicated sufficiency was strongly correlated with causal descriptions linking claim and evidence; when students understood the data it was easier to cite sufficient evidence. Rhetorical reference categories indicated how well students used data in explanations; students were more likely to simply include inscriptions in the text and less likely to interpret specific features of the inscriptions (little data interpretation). The researchers argued that data may have included data perceived important, but students did not include and

explanation out of belief that the teacher already understood data meaning and an explanation was not necessary.

College Science

Three relevant college-level science research studies about scaffolding students' evidence-based explanations about scientific knowledge claims were identified in the literature. Two of the studies used technology-based scaffolding tools and the third study used paper-based scaffolding tools. All three studies were, essentially, pilot studies to investigate how students used the tools and embedded scaffolds to generate explanations.

Zemba-Saul, Munford, Crawford, Friedrichsen, & Land (2002) investigated how preservice science teachers used the BGuILE software module (see high school studies), Galapagos Finches, to construct evidence-based explanations about natural selection. A qualitative case study design was employed for this research. Two pairs of preservice teachers with either science laboratory experience or an advanced degree in science participated in the study.

Results indicated that preservice teachers with advanced science degrees or professional science experience (1) explained links between claims at supporting evidence, (2) generated arguments consistently grounded by evidence from the investigation yet alternate explanations were not explored by one pair and credibility was often established with inadequate evidence, and (3) failed to consider causal variables relevant to natural selection probably due to less than "robust understandings of a Darwinian explanation for change in population traits" (Zemba-Saul et al., 2002, p.

451), and (4) struggled with anomalous data, and resorted to seeking confirming evidence to support their claims. In conclusion, the researchers argued that the preservice teachers received insufficient guidance and support from the instructor, necessary to support explanation construction.

Another college study with preservice teachers investigated how two pairs of non-science majors in an engineering course explained light phenomena using data collected from hands-on experiments with computer-assisted data collection (Land & Zembal-Saul, 2003). Students used experiment pages to document and take notes about data and then used explanation pages to explain the relationship between the claim and the evidence. At the beginning of the study, students accessed the prior knowledge pages and responded to three prompts about light phenomena. Students collected data and then produced computer-generated graphs in an experiment page where the experimental procedure, experimental results, were used to form a claim. Next, students used explanation page to reiterate the claim made on the experiment page, identified relevant evidence and explained how the evidence was linked to the claim. Students interacted with each other during explanation revision and a whole class discussion synthesized the mean outcomes for the module as students presented experimental results and explanations.

Students often generated simple observation-driven explanations continued to do so even after being prompted to evaluate and reconsider the explanation; simply providing scaffolds may not be enough to elicit explanatory statements that go beyond students simply restating observations. Limited background knowledge was suspected

for the observation-driven statements because results indicated that background knowledge helped students “take advantage” (Land & Zembal-Saul, 2003) of the available scaffolds. Students interacted with each other during explanation revision and, jointly synthesized the mean outcomes for the module represented in all experimental results and explanations during a whole class discussion.

In a study with first-year college students enrolled in an introductory oceanography course, Kelly and Takao (2002) investigated student explanations about evidence-based knowledge claims, and how students use data as evidence; most of the students were non-science majors enrolled in an oceanography course. Students were instructed to generate researchable questions, use relevant geological data available on a CD-ROM disk and then use plate tectonics theory to explain how the data are used as evidence to support a scientific knowledge claim. Students generated an 1800-word midterm paper to summarize findings. Soft scaffolds about scientific writing were provided by the lecture professor and by the laboratory teaching assistants; hard scaffolds were embedded in the laboratory manual for the course.

The instructor generated a grading rubric for report quality, and researchers generated a scoring rubric for epistemic level. All student papers were ranked from 1 to 24 using both the instructor-generated rubric and the researcher-generated epistemic levels rubric. Four teaching assistants used the instructor-generated rubric and researchers used the researcher-generated epistemic levels rubric. The teaching assistants' ranks had a statistically significant difference.

A comparison of ranks generated by teaching assistants using the instructor-generated rubric and ranks generated by researchers using the epistemic-levels criteria failed to reach statistical significance for any relationship. The researchers suggest that inconsistency from instructor grading and sensitivity of the epistemic levels argumentation model together resulted in differences in the ranks of the papers.

Students were more likely to produce inferential statements and less like to produce simple observation statements to link theories to data. The researchers were unable to draw conclusions due to inter-rater reliability issues. While both rubrics aimed to qualify students' explanations, scores were statistically different. Inter-rater reliability was very low among instructors (spearman $\rho = .12$) but was reasonably high for agreement between researchers (spearman's $\rho = 0.80$). The low value for instructors is not surprising considering the lack of a systematic approach for reconciling differences early in the process.

Each of the college level studies used scaffolding tools and embedded scaffolds, but all participants received the same treatment in each study. Comparisons were made for students with adequate versus limited prior knowledge in the Land & Zembal-Saul (2003) study; however, case-based methodology was used and only two cases were compared (20 preservice teachers participated in pairs, resulting in data for 10 cases). The third study by Kelly & Takao (2002) did not explicitly describe scaffolding or scaffolds; however, there was a systematic approach whereby guidance was delivered through instructional prompts.

Overall results for the college studies were similar to results for both middle school studies and high school studies. In all studies, students had difficulty using conceptual models or theoretical frameworks to explain how data supported a knowledge-based scientific claim. Interestingly, the Kelly & Takao study compared outcome variable results for the rubric generated by the researchers and the rubric generated by the lecture professor.

Summary

Developing an instructional intervention designed to engage students in model-based reasoning about scientific data requires knowledge about both epistemological reasoning and individual characteristics that influence epistemological reasoning. Two individual characteristics that influence epistemological reasoning and may confound the scaffolding treatment results are epistemological beliefs about scientific knowledge and domain knowledge.

Epistemological Reasoning

Scientists often engage model-based reasoning as they do science but students often engage in phenomenon-based or relation-based reasoning and rarely engage model-based reasoning (Driver et al., 1996). With guidance, however, students demonstrated the capacity to use model-based reasoning to make sense of data and to explain how evidence is used to support a scientific knowledge-based claim (Petrosino et al., 2003; Stephens et al., 1999).

Distributed scaffolding systems helped students engage in some form of epistemological reasoning, evident through their explanations. Studies about hard

scaffolds in a distributed scaffolding system, however, indicated mixed results. For example, when provided domain-specific hard scaffolds college students were more likely to generate inferential statements rather than simple observation statements (Kelly & Takao, 2002) but high school students were more likely to use content knowledge and principles in explanations (Sandoval, 2003). Middle school students that used domain-specific scaffolds were more likely to simply complete assignments (Davis & Linn, 2000). When middle school students used domain-general scaffolds, explanations had considerably more principles and conceptual models than when domain-specific scaffolds were provided (Davis, 2003a). Sandoval (2003) found that when high school students used domain-specific prompts, explanations often included content knowledge and principles; however, Sandoval & Millwood (2005) found when high school students used the same prompts, content knowledge and domain principles were rarely used in explanation justifications.

Some college students and high school students engaged higher order epistemological reasoning levels when domain-specific scaffolds were provided, yet, middle school students appear to simply complete assignments or use simple epistemological reasoning. In other studies with domain-specific scaffolds, college students and high school students use simple epistemological reasoning, similar to the middle school students. In studies where both domain-general and domain-specific scaffolds were used, it was impossible to determine which scaffolding type influenced epistemological reasoning, especially when students' prior knowledge and epistemological beliefs about scientific knowledge were considered by researchers.

Epistemological Beliefs about Scientific Knowledge

Research indicates that differences in students' epistemological beliefs about scientific knowledge compared to scientists' beliefs about scientific knowledge may help explain why scientists use model-based reasoning and students often do not. For example, students with more sophisticated epistemological beliefs about scientific knowledge are more likely to use conceptual models to interpret and make sense of data from scientific experiments (Bell & Linn, 2000; Davis, 2003b; Havdala & Ashkenazi, 2007; Tsai, 1999). Unfortunately, only two of the eleven scaffolding research studies included a measure of epistemological beliefs about scientific knowledge (e.g., Bell & Linn, 2000; Davis, 2003b). Scaffolding studies measuring students' epistemological beliefs about scientific knowledge were not identified for high school or college level students.

When epistemological beliefs about scientific knowledge are considered in the context of explanations about evidence and scientific knowledge claims, it is reasonable to include a context-specific measure (Elby & Hammer, 2001; Sampson & Clark, 2006). The nature of science as argument questionnaire (Sampson & Clark, 2006) was developed to measure epistemological beliefs about scientific knowledge in the context of explanations.

Domain Knowledge

Domain knowledge is the basis for epistemological reasoning about scientific knowledge claims for both scientists and students (Hogan & Maglienti, 2001) and impacts the adequacy of an individual's reasoning within the domain (Metz, 2000).

Students are better able to formulate reasons for why data can be used as evidence to support claims when they are able to comprehend and use relevant domain knowledge (McNeill and Krajcik, 2007; Metz, 2000; Sandoval, 2003).

Domain knowledge is an important variable influencing epistemological reasoning, yet, only three of the eleven scaffolding studies collected data about students' domain knowledge before or after the study, and only one study reported a strong relationship between pretest and posttest knowledge with no main effect from scaffolds condition (McNeill et al., 2006). Another study reported adequate prior knowledge influenced students' abilities to use scaffolds (Land & Zembal-Saul, 2003).

Study Context

This research study addressed four gaps in the science education literature; (1) little is known about the kinds of epistemological reasoning engaged by college students engaged in science laboratory activities, (2) there is no research about the effectiveness of scaffolding to support college students; model-based reasoning about how data are used as evidence, (3) the relationships among domain knowledge, epistemological beliefs about scientific knowledge, and epistemological reasoning are not reported, and (4) research about how scaffolding designed to support model-based reasoning influences knowledge gains is not reported in the literature.

The first gap is about the kinds of epistemological reasoning expressed in college students' scientific explanations about how data are used as evidence. Interview data indicates that college students have difficulty using model-based reasoning (Kelly & Takao, 2002; Land & Zembal-Saul, 2003; Ryder & Leach, 2000; Ryder et al., 1999;

Smith & Wenk, 2006; Zembal-Saul et al., 2002). Yet, research indicates that model-based reasoning can be achieved by middle school (Petrosino et al., 2003) and high school students (Stephens et al., 1999) used instructional scaffolding in situated learning experiences.

The second gap is about the effectiveness of scaffolds facilitating college students' use of model-based reasoning about how data are used as evidence. While studies have attempted to learn more about how scaffolding helps students, the studies do not examine different scaffolding treatments (Sandoval & Millwood, 2005; Stephens, Campbell, & Lucas, 1999; Zembal-Saul et al., 2002)

The third gap is about the relationships among epistemological reasoning, domain knowledge, and epistemological beliefs about scientific knowledge for college students. Researchers emphasize that domain knowledge and epistemological beliefs about scientific knowledge influence epistemological reasoning (e.g., Bell & Linn, 2000; McNeill et al., 2006), however, variable measurements are not reported by researchers.

The fourth gap is about how scaffolding designed for model-based reasoning influences knowledge gains. The literature indicates that students gain conceptual knowledge (Bell & Linn, 2000; McNeill, 2006), use domain knowledge and principles in explanations (Sandoval, 2003; Sandoval & Millwood, 2005), and need substantial prior knowledge to successfully use scaffolds (Land & Zembal-Saul, 2003). Unfortunately, there are no studies that reported how domain-specific and domain-general scaffolding to support model-based reasoning influence knowledge gains.

The purpose of this study was (1) to investigate how scaffolding treatments influence college students' epistemological reasoning about how data are used as evidence, (2) to describe students' epistemological reasoning practice over the course of the study, (3) to learn more about relationships among students' domain knowledge, epistemological beliefs about scientific knowledge, and epistemological reasoning, and (4) to investigate how scaffolding for epistemological reasoning influences knowledge gain.

Four research questions were investigated in this study:

- (1) Does scaffolding treatment influence epistemological reasoning?
- (2) Does epistemological reasoning improve with practice?
- (3) What are the relationships among content knowledge, epistemological beliefs about scientific knowledge, and epistemological reasoning?
- (4) Does scaffolding treatment influence domain knowledge gain?

CHAPTER III

METHODS

Research Design

A partially mixed methods sequential research design with equal status (Johnson & Onwuegbuzie, 2004) was used to investigate college students' epistemological reasoning, influence of scaffolding treatment on epistemological reasoning and knowledge gains, and the relationships among domain knowledge, epistemological beliefs about the nature of scientific knowledge, and epistemological reasoning. A quasi-experimental method was used to randomly assign entire laboratory groups of students to no scaffolds condition, domain-general scaffolds condition, or domain-specific scaffolds condition.

Data were sequentially collected in a quantitative phase, followed by a qualitative phase, and finally a second quantitative phase. In the first quantitative phase, content knowledge and epistemological beliefs about scientific knowledge were collected prior to the study. During the qualitative phase, students answered eight open-ended laboratory activity questions. Finally students' content knowledge was assessed in the quantitative phase after the study. The qualitative and quantitative phases were mixed after completion of the study to clarify the relationship between epistemological reasoning, pretest knowledge, posttest knowledge and epistemological beliefs about scientific knowledge.

Participants

The researcher recruited students enrolled in either GENE 301 or GENE 302 introductory at Texas A&M University in the Fall semester, 2010. One week prior to the beginning of the study, students were asked to voluntarily participate. Students who agreed to participate signed and dated an informed consent form during the recruitment phase. Three hundred and eighty-one students signed consent forms, 315 students submitted all materials in this study.

Experiment 1

One-hundred seventy two undergraduates enrolled in genetics 301 completed all components of the study for Experiment 1 and, just over half were college juniors (see Table 2). Several majors were represented by the Experiment 1 participants (see Table 3).

Table 2

Per cent of participants in each college grade level for Experiment 1

Classification	No Scaffolds N = 40	DG Scaffolds N = 70	DS Scaffolds N = 62	Total N = 172
Sophomore	0.0	1.4	3.2	1.7
Junior	40.0	35.7	50.0	47.9
Senior	60.0	62.9	46.8	56.4
Total	100.0	100.0	100.0	100.0

Table 3
Per cent of participants in each college major for Experiment 1

	No Scaffolds	DG Scaffolds	DS Scaffolds	total
AGEC	0.0	1.4	0.0	0.6
ANSC	37.5	34.3	37.7	36.3
BESC	2.5	2.9	0.0	1.8
BHNR	0.0	1.4	0.0	0.6
CHEM	0.0	1.4	3.3	1.8
EDKI	0.0	0.0	1.6	0.6
ENTO	2.5	4.3	0.0	2.3
FIVS	2.5	1.4	4.9	2.9
FSTC	0.0	1.4	0.0	0.6
GEST	2.5	0.0	1.6	1.2
HLTH	5.0	4.3	3.3	4.1
KINE	0.0	2.9	1.6	1.8
NUSC	22.5	24.3	24.6	24.0
POSC	12.5	1.4	3.3	4.7
PSYC	2.5	0.0	3.3	1.8
WFSC	10.0	18.6	14.8	15.2
Total	100.0	100.0	100.0	100.0

Note. DG = *Domain-general*, DS = *Domain-specific*

Experiment 2

One-hundred forty three undergraduates enrolled in genetics 302 completed all components of the study in Experiment 1. Just over one-half of the participants were ranked as college juniors (see Table 4). Several college majors were represented by the Experiment 1 participants (see Table 5); most students were Biology majors.

Table 4

Per cent of participants in each college grade level for Experiment 2

	No Scaffolds	DG Scaffolds	DS Scaffolds	Total
Classification	N = 51	N = 41	N = 51	N = 143
Sophomore	5.9	7.3	11.8	8.4
Junior	41.2	65.9	49.0	51.0
Senior	52.9	26.8	39.2	40.6
Total	100.0	100.0	100.0	100.0

Note. DG = *Domain-general*, DS = *Domain-specific*

Table 5

Per cent of participants in each college major for Experiment 2

	No Scaffolds	DG Scaffolds	DS Scaffolds	total
BICH	5.9	7.3	15.7	9.8
BIMS	0.0	0.0	2.0	0.7
BIOL	64.7	68.3	62.7	65.0
BMCB	1.8	7.3	7.8	9.1
CHEN	2.0	0.0	0.0	0.7
GENE	9.8	7.3	5.9	7.7
MBIO	2.0	4.9	3.9	3.5
ZOOL	3.9	4.9	2.0	3.5
Total	100.0	100.0	100	100.0

Note. DG = *Domain-general*, DS = *Domain-specific*

Materials

Instructional Context

Introductory Genetics is offered as two separate courses; GENE 301 and GENE 302. According to the 2010-2011 Texas A&M University course catalog, Genetics 301 (Comprehensive Genetics) is open to all majors except those in Biochemistry or Genetics, and Genetics 302 (Principles of Genetics) is designed for Biochemistry,

Genetics, and all Biology majors. Both courses cover basic principles of genetics, including Mendelian inheritance; however, Genetics 302 exclusively stresses evolutionary genetics processes described at the molecular level. Genetics 302 students are exposed to more in-depth material at a faster pace than students in Genetics 301.

Instructional Setting. Each laboratory classroom had a projector system used to deliver PowerPoint presentations during laboratory recitation prior to each activity. Teaching assistants met each Friday, one week prior to the corresponding laboratory procedure, reviewed instructional materials and discussed instructional strategies. The laboratory instruction was equivalent for all laboratory sections; PowerPoint presentations delivered during the course of this study were the same for both genetics courses. Each PowerPoint presentation presented conceptual knowledge about the laboratory activity. Following the PowerPoint presentation, teaching assistants illustrated example data and demonstrated the use of model-based reasoning to explain the data.

Departmental laptop computers were used during this study. Sixteen laptops (one for each set of two students) were placed in each laboratory classroom prior to the beginning of lab. The operating system on the laptops was either Windows Vista (32-bit) or Windows XP.

Software Simulations (Computer-Simulated Experiments). The Bioquest Consortium software, Case it v6.04© (University of Wisconsin, 2010) was used in this study. Case it v6.04© is a National Science Foundation supported project with case-based scenarios to contextualize data analysis and data interpretation. Case it v6.04© is free to educational institutions for educational purposes and can be freely downloaded

for educational purposes. Prior to use in this study, the software protocol was informally tested with college students; software bugs were identified and corrected by the software programmers prior to the study implementation. The virtual laboratory equipment (see Figure 2) appeared similar to actual laboratory equipment used in the hands-on experiments. Examples of computer-simulated data (see Figure 3) and hands-on data (see Figure 4) illustrate how the computer-simulated experimental data illustrates a less messy version of real data.



Figure 2. Screenshot of Case It!© software with electrophoresis laboratory equipment.

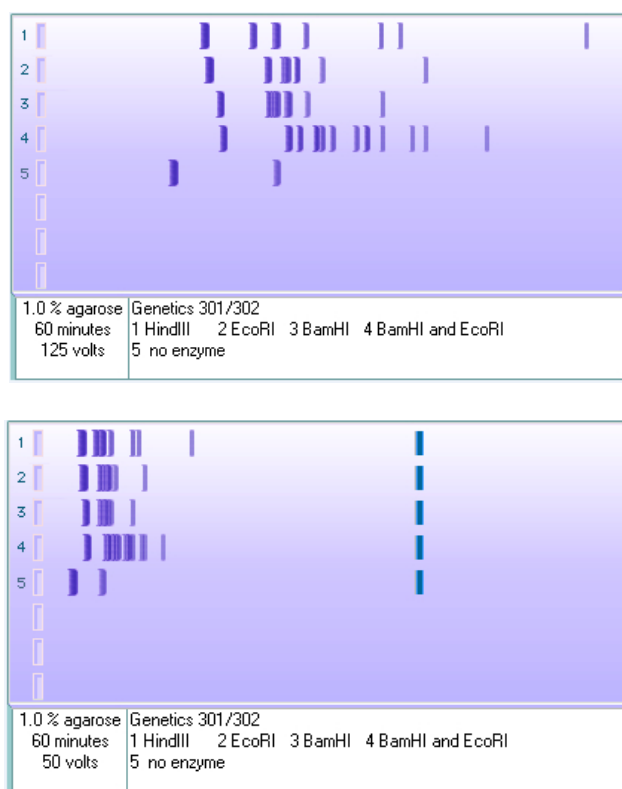


Figure 3. Computer-simulated experimental data for activity 1.

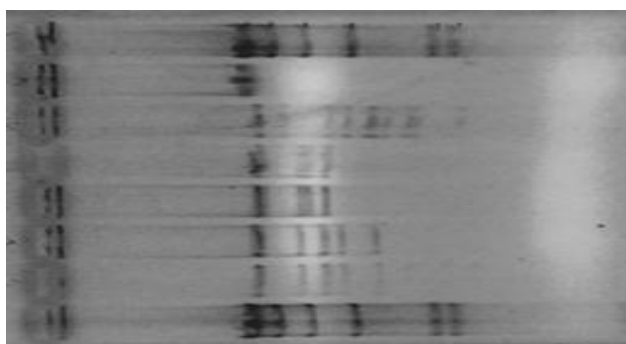


Figure 4. Sample hands-on experimental data for activity 1.

Laboratory Manual. All instructional resources for the laboratory activities were included with the Laboratory Manuals for GENE 301 and GENE 302. The laboratory manual presented core conceptual knowledge necessary for each laboratory exercise plus laboratory protocols followed by questions to be answered in the laboratory report. Four laboratory activities in the laboratory manual were used for this study; 1) *Standard Curves* (computer simulated experiment about restriction digestions and agarose gel electrophoresis), 2) *Restriction Enzyme Digestion of Plasmid DNA* (hands-on experiment about restriction digestions and agarose gel electrophoresis), 3) *Genetically Modified Organisms (GMOs): Bt corn case study* (computer-simulated experiment about PCR amplification of a plant gene and an inserted gene followed by a virtual agarose gel electrophoresis of PCR products); and 4) *Genetically Modified Organisms (GMOs): GMO Experimental Protocol* (a hands-on experiment about PCR amplification of a plant gene and inserted genes followed by agarose gel electrophoresis of PCR products).

Scaffolding Design for This Study

A distributed scaffolding system (Puntambekar & Kolodner, 2004) was used for this study; scaffolding included a technology-based scaffolding tool, a paper and pencil-based scaffolding tool, soft scaffolds provided by the teaching assistants, and hard scaffolds provided as written conceptual prompts designed to help students think about relevant conceptual models to include with explanations about how data are used as evidence.

All students receive to the technology-based scaffolding tool, the paper-based scaffolding tool, and teaching assistants soft scaffolds; the manipulated variable was the

hard scaffolds. The technology-based scaffolding tool was a computer simulated experiment to help students visualize complex data patterns resulting from a molecular biology laboratory technique. The paper-based scaffolding tool was the lab manual with laboratory procedures, domain knowledge resources, and questions provided for each laboratory activity (see Figure 5). Teaching assistants provided soft scaffolds to support students' model-based reasoning during data interpretation. The manipulated variable was the hard scaffolds. See Figure 5 for the distributed scaffolding system in this study.

This study used three treatments for hard scaffolds; no scaffolds, domain-general scaffolds, or domain-specific scaffolds. The domain-general and domain-specific hard scaffolds were conceptual prompts (Hannafin et al., 1999) designed to help students draw links between conceptual knowledge and explanations about how data are used as evidence (Stephens et al., 1999). To reduce the potential influence of a Hawthorne effect, all groups were instructed to consider all materials presented in the laboratory manual, the laboratory recitations, and the lecture course to support their explanations about how observed data are used as evidence. See Table 6 for scaffolds used in this research.

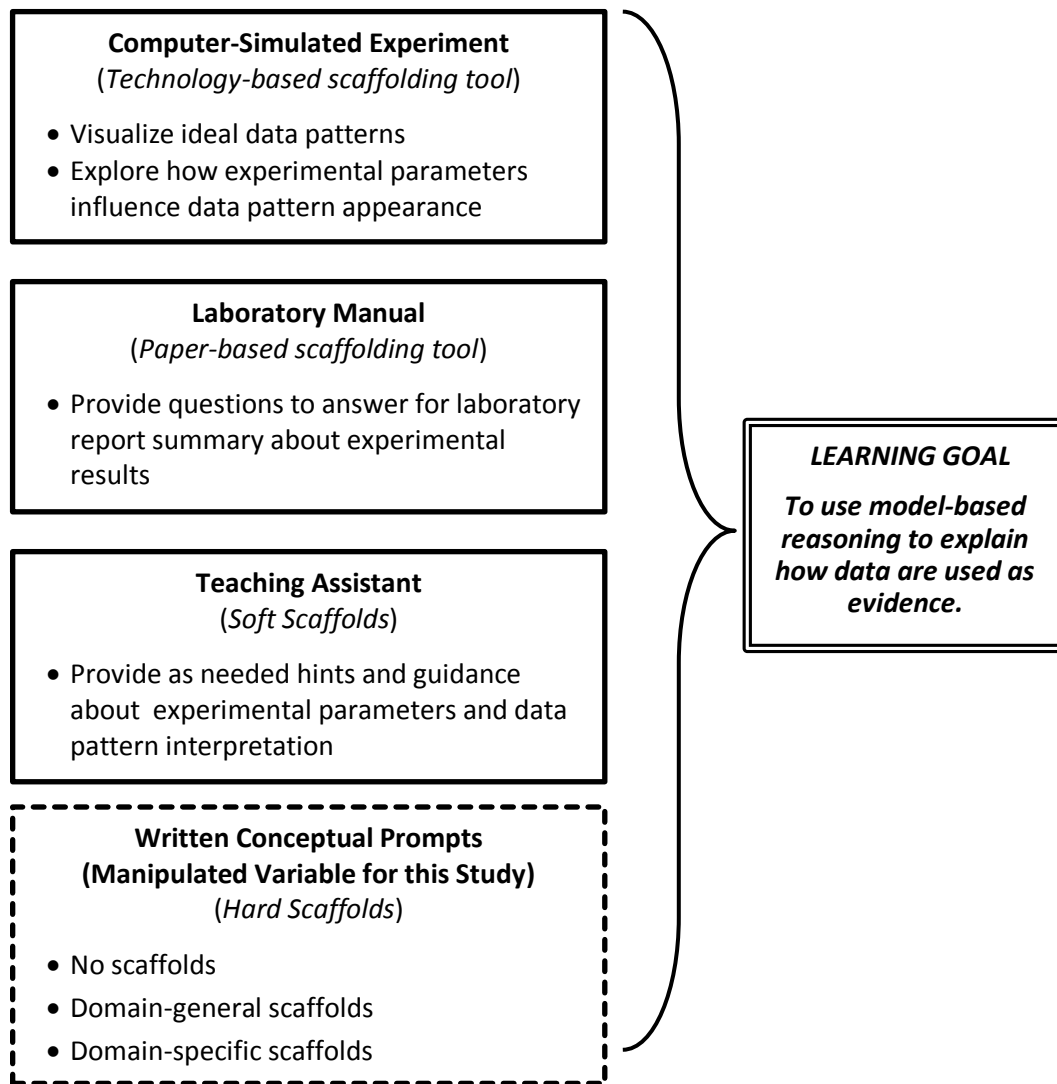


Figure 5. Distributed scaffolding system framework used to synergistically support achievement of the learning goal for this study.

Table 6

No scaffolds, domain-general scaffolds and domain-specific scaffolds for each activity

Activity	No Scaffolds	Domain-General Scaffolds	Domain-Specific Scaffolds
A1 Computer-Simulated Experiment	When answering the questions in your lab report, try to include information provided in lab, in the lab manual, and in your lecture course.	<p>When answering the questions in your lab report, try to include information provided in lab, in the lab manual, and in your lecture course.</p> <p>Completing these sentences may help you think about information to include:</p> <p>Important experimental parameters to consider for data analysis include ____.</p> <p>Data patterns result from ____.</p>	<p>When answering the questions in your lab report, try to include information provided in lab, in the lab manual, and in your lecture course.</p> <p>Completing these sentences may help you think about information to include in your explanations:</p> <p>The DNA fragments separate according to size because ____.</p> <p>The number of DNA fragments in each lane is caused by ____.</p>
A1 Hands-On Experiment	When answering the questions in your lab report, try to include information provided in lab, in the lab manual, and in your lecture course.	<p>When answering the questions in your lab report, try to include information provided in lab, in the lab manual, and in your lecture course.</p> <p>Completing these sentences may help you think about information to include in your explanations:</p> <p>Important experimental parameters to consider for data analysis include ____.</p> <p>An experimental standard is used because ____.</p>	<p>When answering the questions in your lab report, try to include information provided in lab, in the lab manual, and in your lecture course.</p> <p>Completing these sentences may help you think about information to include in your explanations:</p> <p>The DNA fragments separate according to size because ____.</p> <p>The MW standard is included in the plasmid DNA digestion experiment because ____.</p>

Table 6, *continued*

Activity	No Scaffolds	Domain-General Scaffolds	Domain-Specific Scaffolds
A2 Computer-Simulated Experiment	When answering the questions in your lab report, try to include information provided in lab, in the lab manual, and in your lecture course.	<p>When answering the questions in your lab report, try to include information provided in lab, in the lab manual, and in your lecture course.</p> <p>Completing these sentences may help you think about information to include in your explanations:</p> <p>Important experimental parameters to consider for data analysis include _____. Experimental controls are used because _____.</p>	<p>When answering the questions in your lab report, try to include information provided in lab, in the lab manual, and in your lecture course.</p> <p>Completing these sentences may help you think about information to include in your explanations:</p> <p>DNA fragments separate according to size because _____. Positive and negative controls are used in PCR experiments because _____.</p>
A2 Hands-On Experiment	When answering the questions in your lab report, try to include information provided in lab, in the lab manual, and in your lecture course.	<p>When answering the questions in your lab report, try to include information provided in lab, in the lab manual, and in your lecture course.</p> <p>Completing these sentences may help you think about information to include in your explanations:</p> <p>Important experimental parameters to consider for data analysis include _____. Experimental controls are used because _____.</p>	<p>When answering the questions in your lab report, try to include information provided in lab, in the lab manual, and in your lecture course.</p> <p>Completing these sentences may help you think about information to include in your explanations:</p> <p>DNA fragments separate according to size because _____. Positive and negative controls are used in PCR experiments because _____.</p>

Measures

Four measures were obtained from students; first the domain knowledge quiz was administered prior to the study as a pretest, second domain knowledge quiz was administered after the study as a posttest, third the epistemological beliefs about scientific knowledge variable was measured before the study, and fourth epistemological reasoning was repeatedly measured during the study.

Domain Knowledge Quiz (Pretest and Posttest)

Students' pretest domain knowledge about concepts relevant to electrophoresis, restriction digests, PCR and genetically modified organisms was measured using a multiple choice questionnaire (see Appendix) collaboratively designed by the Genetics Laboratory Coordinator and the researcher and reviewed by at least one Genetics lecture professor. Content validity was established by two content experts. Instrument language readability was tested by four students who were not in the genetics courses. The domain knowledge quiz was also administered as a posttest after study completion.

Epistemological Beliefs About Scientific Knowledge

Sampson and Clark's Nature of Science as Argument Questionnaire was used to measure epistemological beliefs about scientific knowledge (see Appendix); the questionnaire was presented at the 2006 Annual conference for the National Association of Research in Science Teaching. Like Toulmin (1958, 2004) and Driver et al. (1996), Sampson and Clark envision argumentation as explanation (c.f., Lawson, 2005; 2010) and the questionnaire was found to be a suitable instrument for this study. Data from this questionnaire was analyzed and results contributed to Research Question 3 analysis.

Sampson and Clark (2006) reported Cronbach's alpha reliability for the questionnaire was 0.70 when tested by 203 high school participants and test-retest reliability was 0.88 ($p=0.01$) for 67 students. Additional testing with experts and novices revealed that experts scored higher ($M=128.1$, $SD = 13.9$), as a group, than novices ($M=93.5$, $SD = 12.4$). The design and validation of the Nature of Science as Argument Questionnaire was presented at the 2006 National Association of Research in Science Teaching (NARST) conference by Sampson and Clark (2006). In another study, Weinberger, Sampson, Jaspars, and Fischer (2006) did not report reliability for student scores. The questionnaire has not been published in a journal publication

Epistemological Reasoning

For this study, Driver et al.'s (1996) epistemological reasoning framework was expanded to include two intermediate levels (see Table 7); one level was added between phenomenon-based reasoning and relation-based reasoning, and the other level was added between relation-based reasoning and model-based reasoning. Each of the eight laboratory report questions answered by students was coded using the modified framework.

Table 7

Modified Driver et al. (1996) framework for coding epistemological reasoning

Explanation Category and Description	Language of Explanation (Adapted from Driver et al., 1996)
(1) Phenomenon-based explanations are simple re-descriptions of the phenomenon; the data are self-explanatory.	“students make no distinction between observation and explanations; explanations are a re-description of events” (p. 141). The goal is making observations and seeing what happens. For example, the bands end up farther apart
(1.5) Intermediate for Relation-based and Model-based	Includes elements of both levels (1) and (2)
(2) Relation-based explanations are generalizations that emerge from the data; the data are no longer self-explanatory.	Students “distinguish between observation and explanation, but the explanation is seen as a generalization emerging from the data, a general ‘pattern’ in the data” (p. 141). The goal is to identify a generalization. For example, the higher the voltage, the farther apart the bands in a lane, or, the voltage pushes smaller bands farther than larger bands.
(2.5) Intermediate for Relation-based and Model-based	Includes elements of both levels (2 and 3).
(3) Model-based explanations are models of the phenomenon and “predictions from the model can be checked against observations” (p. 141).	Students “distinguish between observation and explanation” (p. 141). The goal is to explain the data patterns using a model. For example, because the DNA has such a strong negative charge, an increase in voltage applies greater force to the DNA and pushes it through the porous agarose and the DNA fragments are separated according to molecular size with larger DNA molecules less able to navigate through agarose gel pores, traveling less distance than smaller DNA molecules over the same time period.

The researcher explained the coding scheme to a colleague, and then used the framework to code three student responses. All coding was blind to student identity. After reconciling any discrepancies, the raters continued to code the data for each question. The process of coding and reconciling discrepancies between coders was performed with 3 sample questions, next 10 samples from each question was coded and the process was repeated for student answers to each laboratory report question. Eighty questions were coded (a sample of 10 from each of the 8 questions). The researcher and colleague reached an inter-rater reliability value of 94%.

Procedures

On the first day of the study, the Nature of Science as Argumentation Questionnaire (Sampson & Clark, 2006) survey and the Knowledge Quiz were administered using paper and writing utensil. Next, all students completed two assignments; Activity 1 was about cutting DNA into smaller pieces (Restriction Digests, enzymes were used to cut DNA into fragments) and electrophoresis (physically separating the fragments according to size) and activity 2 was about amplifying the number of explicit pieces of DNA (Polymerase Chain Reaction or PCR) and electrophoresis. Each activity was performed using two media; first a computer-simulated experiment followed by an equivalent hands-on experiment. Due to time limitations and the brevity of the computer-simulated experiment for activity 2, both the computer simulation and the hands-on experiments were performed during a single lab period. Each laboratory period was 2 hours and 50 minutes long. Students were completed assigned activities and submitted answers to laboratory report questions prior

to leaving the laboratory classroom. After students completed activity 2, the knowledge posttest quiz was administered.

Students performed a computer-simulated experiment prior to a equivalent hands-on experiment; there were two laboratory activities (see Figure 6). During recitation prior to each laboratory activity, teaching assistants provided soft scaffolds to assist students with both the computer-simulated experiments, and the equivalent hands-on experiments. For the computer-simulated experiments, teaching assistants modeled the use of software features. For example, teaching assistants demonstrated how to take pictures of the virtual data to compare data patterns resulting from varied experimental parameters. For the hands-on experiments, teaching assistants demonstrated various troubleshooting techniques and used model-based reasoning to explain data patterns for students.

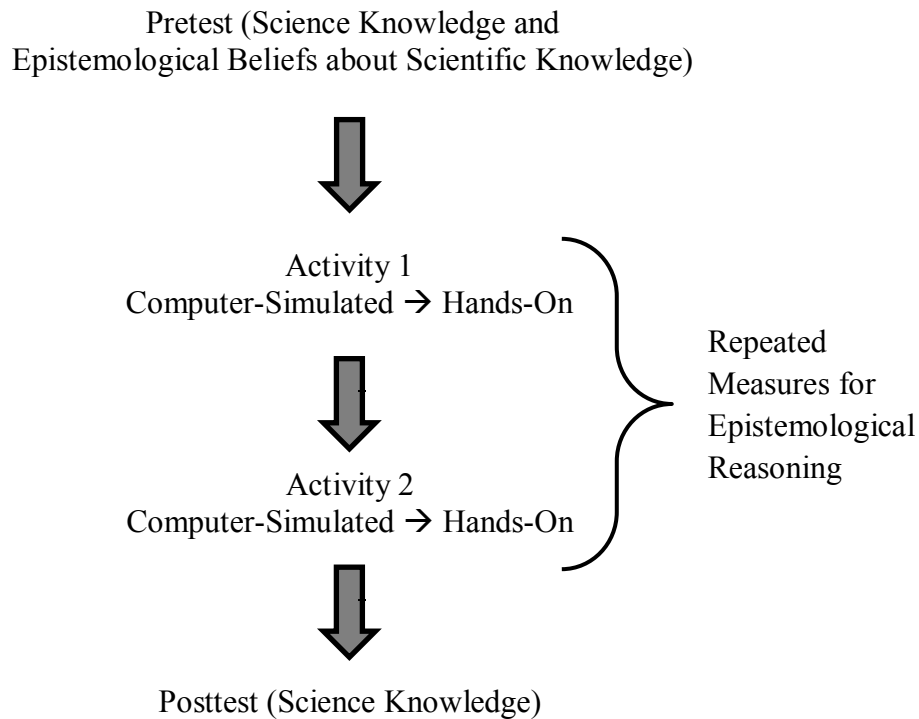


Figure 6. Overview of study procedures.

Experiment 1

The scope and sequence of the two introductory genetics courses was not identical; genetics 301 (Experiment 1) was slower in pace with reduced coverage of topics as compared to those in genetics 302 (Experiment 2). Participants in Experiment 1, therefore, completed this study one week later than Experiment 2 participants, after the Thanksgiving holiday. When materials were distributed for the last set of laboratory activity questions, the correct form for question seven was inadvertently not provided to students in two of the laboratory sections. As a consequence, only seven of the eight questions were analyzed in the Experiment 1 results.

Experiment 2

Genetics 302 participants in Experiment 2 completed all procedures as identified in the general procedures identified earlier in this chapter. The time line for Experiment 2 did not include the delay in laboratory activities to adjust for the pace of lecture materials (see Experiment 1 Procedure), and the final activity was performed the week before the Thanksgiving holiday.

CHAPTER IV

RESULTS

This chapter presents the analysis of data included in this study. Three scaffolding treatments were: no scaffolds, domain-general scaffolds, and domain-specific scaffolds. The primary purposes of this study were to investigate the influence of scaffolding treatment on epistemological reasoning and to investigate how prior (pretest) knowledge and epistemological beliefs about scientific knowledge are related to epistemological reasoning.

Research Questions

Four Research Questions were addressed in this study:

- (1) Does scaffolding treatment influence epistemological reasoning?
- (2) Does epistemological reasoning improve with practice?
- (3) What are the relationships among content knowledge, epistemological beliefs about scientific knowledge, and epistemological reasoning?
- (4) Does scaffolding treatment influence domain knowledge gain?

Research Question 1:

Does Scaffolding Treatment Influence Epistemological Reasoning?

In order to answer Research Question 2, epistemological reasoning scores were summarized by scaffolding treatment, and Chi square analysis was performed. Due to the number of cells with expected frequencies less than five, the Yates (1934) correction was used to combine levels 2.0 and 2.5. The Yates correction does not distort data when

the chi square table is greater than a 2 x 2, and Yates reduces the probability of a type I error.

Experiment 1

Graphical representation of epistemological reasoning by scaffolding treatment (see Figure 7) indicated very similar results for the three scaffolding treatment groups. Chi square results for Experiment 1 students indicated 25% of the cells had an expected count less than five; the Yates correction was used to combine epistemological reasoning levels 2.0 and 2.5. The Yates corrected chi square results indicated no statistically significant differences in epistemological reasoning by scaffolding treatment, $\chi^2 = 2.09$, $df = 4$, $p = 0.72$.

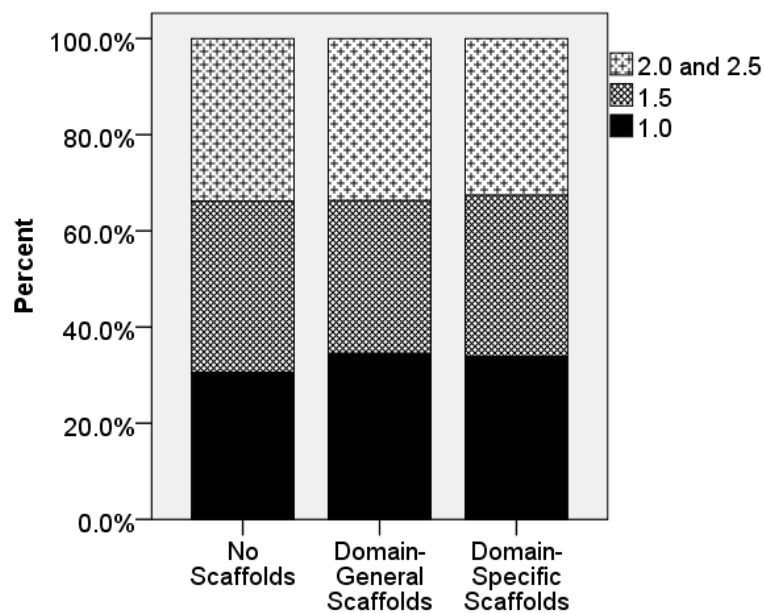


Figure 7. Epistemological reasoning levels by scaffolding treatment for Experiment 1 participants.

Experiment 2

Graphical representation of epistemological reasoning by scaffolding treatment (see Figure 8) indicated very similar results for the three scaffolding treatment groups. Chi square results for Experiment 2 students indicated 8% of the cells had an expected count less than five, so the Yates correction was used to combine epistemological reasoning levels 2.0 and 2.5. The Yates corrected chi square results indicated no statistically significant differences in epistemological reasoning by scaffolding treatment, $\chi^2 = 1.99$, $df = 4$, $p = 0.74$.

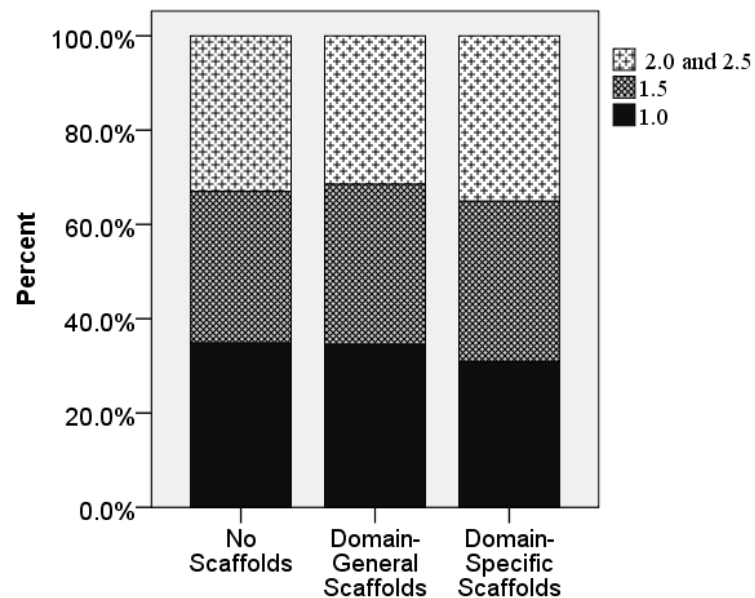


Figure 8. Epistemological reasoning levels by scaffolding treatment for Experiment 2 participants.

Research Question 2:

Does Epistemological Reasoning Improve with Practice?

To investigate scaffolding influences and possible changes in epistemological reasoning over the course of the study, all coded laboratory report questions were considered. Analysis of variance with repeated measures was used to test for differences in epistemological reasoning for the three scaffolding treatment groups. Question 7 was included with Experiment 2 data. Due to an error made when distributing the handouts to students in two laboratory sections, one question was eliminated from Experiment 1..

Experiment 1

The homogeneity of covariance assumption was violated; Mauchly's test of sphericity was significant, Mauchly's $W = .83$, $df = 20$, $p = 0.05$. When Mauchly's test for sphericity is statistically significant, an acceptable correction is produced through the Greenhouse-Geisser epsilon to adjust the degrees of freedom to generate a conservative F-test. The Greenhouse-Geisser correction indicates statistically significant results for the within-subjects effects, $F(5.579, 942.85) = 159.61$, $p < .000$, partial $\eta^2 = .49$. Again, epistemological reasoning was coded highest for question 4. Epistemological reasoning did not improve over time for participants in any scaffolding treatment. Results suggest a statistically significant within subjects difference mostly from question 4 (see Table 8).

The Spearman rho correlation coefficient was $-.078$, indicating a very small indirect relationship, however, statistical significance was not reached, $p = .310$. Epistemological reasoning did not improve over the timeframe of this research.

Table 8
Experiment 1 descriptive statistics for epistemological reasoning by scaffolding treatment

	No Scaffolds N = 40		Domain- General Scaffolds N = 70		Domain- Specific Scaffolds N = 62		Total N = 172	
Item	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Question 1	1.280	0.251	1.300	0.287	1.246	0.322	1.276	0.292
Question 2	1.207	0.273	1.293	0.313	1.222	0.281	1.247	0.293
Question 3	1.146	0.230	1.179	0.341	1.167	0.237	1.167	0.281
Question 4	1.988	0.136	1.929	0.322	1.929	0.267	1.943	0.268
Question 5	1.415	0.402	1.279	0.337	1.198	0.292	1.282	0.346
Question 6	1.134	0.274	1.229	0.291	1.238	0.282	1.210	0.285
Question 8	1.232	0.253	1.014	0.120	1.206	0.343	1.135	0.270

Experiment 2

The homogeneity of variance assumption was violated for the analysis of variance with repeated measures. Mauchly's test of sphericity was significant for the repeated measures epistemological reasoning scores Mauchly's $W = .90$, $df = 27$, $p = 0.002$. The Greenhouse-Geisser correction was used and indicated significant results for the within subjects effects, $F(6.33, 885.84) = 113.75$, $p < .000$, partial $\eta^2 = .49$. Epistemological reasoning was greatest for question 4; however, the mean scores for successive questions did not consistently improve over the course of this study.

Epistemological reasoning did not improve over time for participants in any scaffolding treatment. Results suggest a statistically significant within subjects difference; however, mean scores did not consistently improve except for question 4 (see

Table 9). The Spearman rho correlation coefficient was .105, indicating a very small direct relationship, however, statistical significance was not reached, $p = .217$.

Table 9

Experiment 2 descriptive statistics for epistemological reasoning by scaffolding treatment

	None N = 51		DG N = 41		DS N = 51		Total N = 143	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Question 1	1.314	.299	1.354	.279	1.480	.387	1.385	.334
Question 2	1.373	.297	1.378	.217	1.422	.272	1.392	.266
Question 3	1.098	.245	1.171	.240	1.137	.284	1.133	.258
Question 4	1.900	.300	1.927	.286	1.804	.333	1.874	.311
Question 5	1.333	.294	1.268	.300	1.451	.350	1.357	.323
Question 6	1.255	.289	1.354	.358	1.206	.303	1.266	.319
Question 7	1.176	.280	1.122	.217	1.216	.287	1.175	.267
Question 8	1.118	.280	1.022	.078	1.108	.231	1.084	.197

Note. None = No Scaffolds, DG = Domain-General, and DS = Domain-Specific

Research Question 3:

What Are the Relationships Among Content Knowledge, Epistemological Beliefs About Scientific Knowledge, and Epistemological Reasoning?

Average epistemological reasoning scores, average pretest knowledge scores, and epistemological beliefs about scientific knowledge (NSAAQ) scores were used to answer Research Question 4. Pearson bivariate correlation coefficients were calculated to determine relationships among measured variables.

Domain Knowledge

Experiment 1. Pretest and posttest score distributions were normally distributed (see Figure 9). Homogeneity of variance was met, Box's M , (6, 241.90) = 10.80, p = .10).

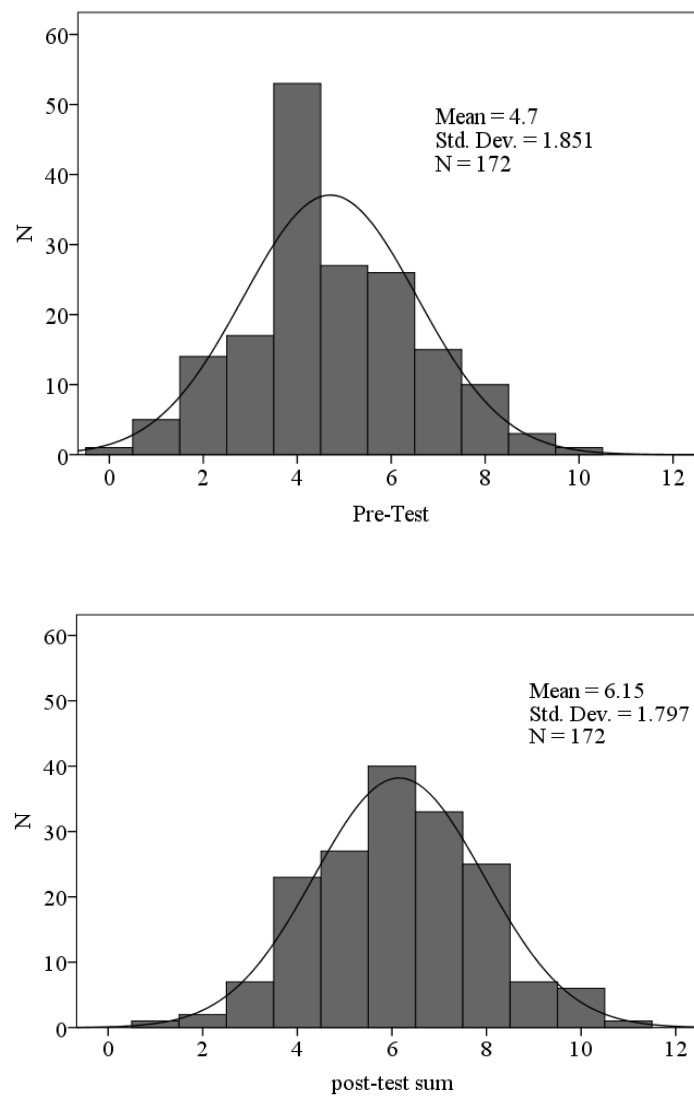


Figure 9. Pretest and posttest knowledge score distributions for Experiment 1.

Experiment 2. Pretest and posttest scores were normally distributed (see Figure 10). The data satisfied the assumption of homogeneity of variance, Box's $M(6, 372409.70) = 2.38; p = .89$.

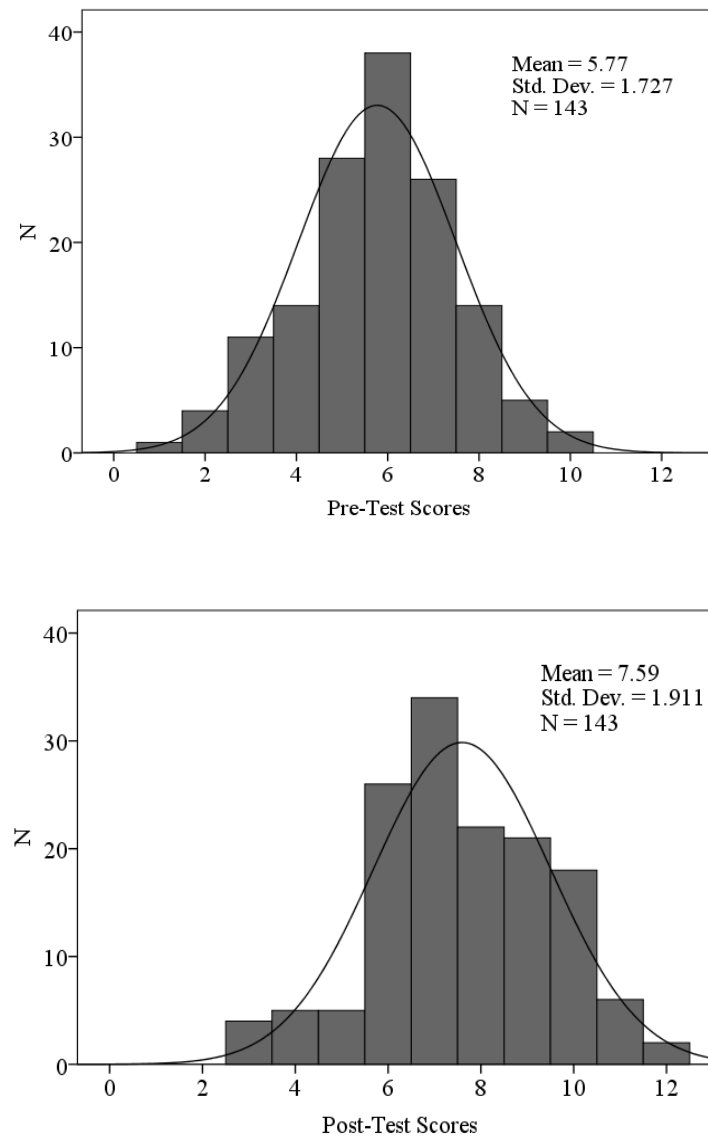


Figure 10. Pretest and posttest knowledge score distributions for Experiment 2.

Epistemological Beliefs about Scientific Knowledge

Experiment 1. Reliability analysis for epistemological beliefs about scientific knowledge indicated low internal consistency items were included in the analysis for this group participants; Cohen's alpha was .526. When items 3, 9, and 10 were systematically excluded from analysis, Cronbach's alpha increased to .605. Participant scores ranged from 65 to 106 and scores were normally distributed for Experiment 1 participant (see Figure 11).

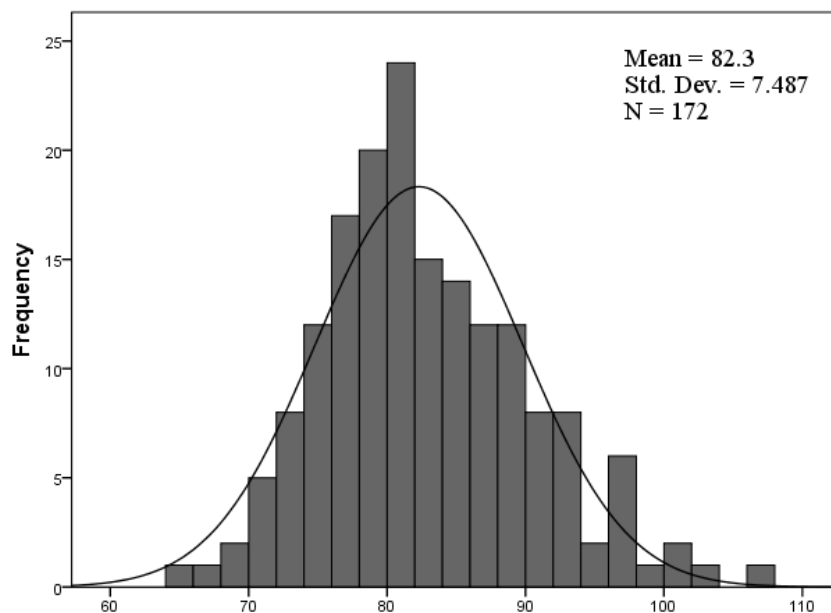


Figure 11. Experiment 1 score distribution for epistemological beliefs about scientific knowledge.

Experiment 2. In Experiment 2, participants' scores for epistemological beliefs about scientific knowledge ranged from 63 to 109 and scores were normally distributed for Experiment 1 participants. (see Figure 12). Reliability analysis for all items indicated low internal consistency for the instrument with this group participants; Cohen's alpha was .605. After systematically removing items 3, 9, and 10 Cronbach's alpha increased to .71; an acceptable value for internal consistency.

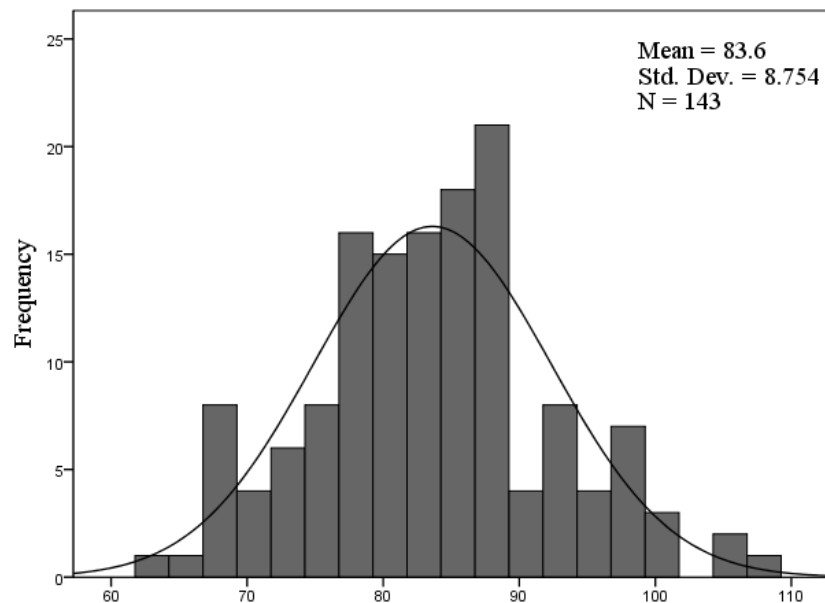


Figure 12. Experiment 2 score distribution for epistemological beliefs about scientific knowledge.

Epistemological Reasoning

Individual student responses across the seven laboratory report questions were consistent for all Experiment 1 participants' coded explanations (Cronbach's $\alpha = .994$). The average epistemological reasoning was, therefore, used to answer Research Question 3, and the average epistemological reasoning scores were normally distributed (see Figure 13).

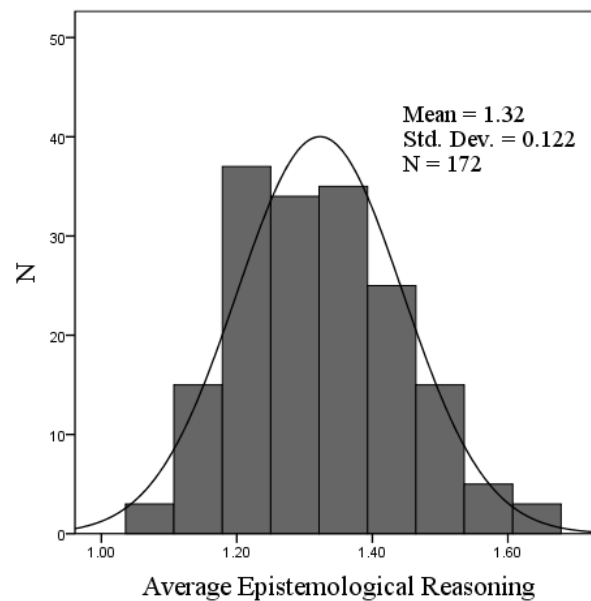


Figure 13. Experiment 1 average epistemological reasoning score distribution.

Because individual student responses across the eight laboratory report questions were consistent for all participants in Experiment 2 (Cronbach's $\alpha = .991$), the

average epistemological reasoning was used to determine if there was a main effect difference for scaffolding treatment. The distribution of the average epistemological reasoning scores was normal (see Figure 14).

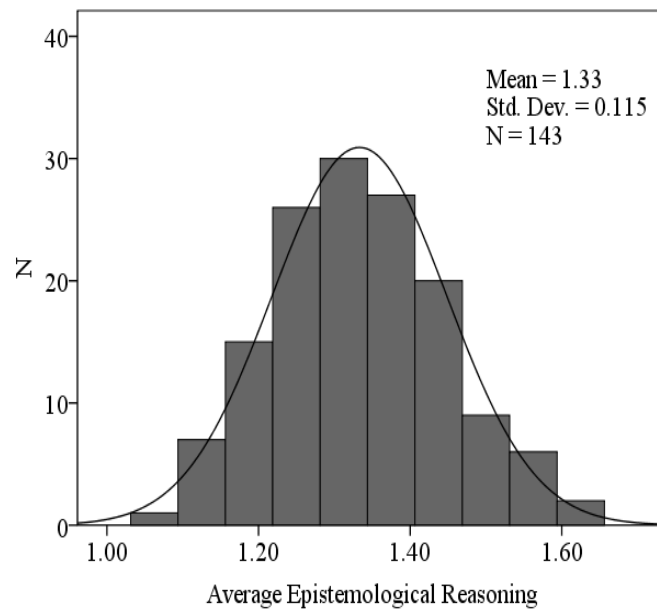


Figure 14. Experiment 2 average epistemological reasoning score distribution.

Experiment 1. Statistical significance was not reached for 2 sets of variables; (1) pretest knowledge and epistemological reasoning, and (2) posttest knowledge and epistemological beliefs about scientific knowledge. Statistically significant positive bivariate correlations were determined for all other possible variable pairs. (see Table 10).

Table 10

Bivariate correlations among pretest knowledge, posttest knowledge, epistemological beliefs, and epistemological reasoning for Experiment 1

		Reasoning	Beliefs	Pretest Knowledge	Posttest Knowledge
N = 143	Epistemological Reasoning	----			
	Epistemological Beliefs	.189*	----		
	Pretest Knowledge	.131	.257**	----	
	Posttest Knowledge	.201**	.128	.381***	----

Note. * $p < .05$, ** $p < .01$, *** $p < .00$, DG = Domain-General and DS = Domain-Specific

Experiment 2. Statistical significance was not reached for the Pearson bivariate correlation coefficients for epistemological beliefs and epistemological reasoning and was not reached for epistemological beliefs and pretest knowledge. There were statistically significant bivariate relationships for all other variable pairs (see Table 11).

Table 11

Bivariate correlations among pretest knowledge, posttest knowledge, epistemological beliefs, and epistemological reasoning for Experiment 2

		Reasoning	Beliefs	Pretest Knowledge	Posttest Knowledge
N = 143	Epistemological Reasoning	----			
	Epistemological Beliefs	-.035	----		
	Pretest Knowledge	.185*	.123	----	
	Posttest Knowledge	.270*	.256**	.403**	----

Note. * $p < .05$, ** $p < .01$

Research Question 4:

Does Scaffolding Treatment Influence Domain Knowledge Gain?

The knowledge quiz scores (pretest/posttest) were used to answer Research Question 1. Statistical analyses conducted were, analysis of variance and analysis of covariance.

Experiment 1

Descriptive statistics for the pretest, posttest, and posttest scores corrected for pretest knowledge the three scaffolding treatment groups for Experiment 1 are shown in Table 12.

Table 12

Experiment 1 descriptive statistics for pretest knowledge scores, posttest knowledge scores, and corrected posttest scores

	N	Pretest		Posttest			
		Mean	SD	Obtained		Corrected	
				Mean	SD	Mean	SE
No Scaffolds	40	4.88	2.10	5.95	1.97	5.82	.257
DG Scaffolds	70	4.76	1.73	6.51	1.78	6.50	.194
DS Scaffolds	62	4.53	1.83	5.89	1.67	5.95	.207
Total	172	4.72	1.85	6.16	1.81	6.14	

Analysis of covariance was used to test the effect of scaffolding treatment after controlling for pretest scores. The homogeneity of variance assumption was met, as indicated by Levene's test, $F(2, 169) = 1.21, p = .30$. Results indicated no significant differences for scaffolding treatment, $F(2, 166) = 4.97, p = .008$, partial $\eta^2 = .06$, $MSE = 13.07$, and the pretest scores covariate had a significant effect on posttest scores, $F(1, 166) = 33.27, p < .00$, partial $\eta^2 = .17$, $MSE = 87.52$.

Experiment 2

Descriptive statistics for the pretest scores, posttest scores, and posttest scores corrected for pretest knowledge the three scaffolding treatment groups for Experiment 2 are shown in Table 13. Analysis of covariance was used to test if a difference existed in posttest scores after controlling for pretest scores. The homogeneity of variance assumption was met, Levene's test, $F(2, 140) = .18, p = .84$. Results indicated no significant differences among scaffolding treatments, $F(2, 137) = .34, p = .72$, partial $\eta^2 = .01$; however, the pretest scores covariate had a significant effect on posttest scores, $F(1, 137) = 26.07, p < .000$, partial $\eta^2 = .16$, $MSE = 82.19$. The instruction produced learning, but the use of scaffolds did not influence knowledge gains.

Table 13

Experiment 2 descriptive statistics for pretest knowledge scores, posttest knowledge scores, and corrected posttest scores

	N	Pretest		Posttest			
		Mean	SD	Obtained		Corrected	
				Mean	SD	Mean	SE
No Scaffolds	51	5.96	1.61	7.82	1.75	7.75	.25
DG Scaffolds	41	5.71	1.91	7.24	2.01	7.27	.28
DS Scaffolds	51	5.63	1.70	7.65	1.98	7.71	.25
Total	143	5.77	1.73	7.59	1.91	7.62	

Note. DG = Domain-General, DS = Domain-Specific

CHAPTER V

DISCUSSION AND CONCLUSIONS

The primary purpose of this research was to investigate the influence of domain-specific and domain-general scaffolds on students' epistemological reasoning while constructing explanations about how data are used as evidence, and to investigate how prior knowledge and epistemological beliefs about scientific knowledge are related to epistemological reasoning. Finally, how domain-general and domain-specific scaffolds influenced domain knowledge gain was investigated.

Two quasi-experimental studies were conducted with the major difference being the undergraduate students who participated (Experiment 1: non-majors; Experiment 2: majors). This chapter presents the findings of the two studies organized by the four research questions that were investigated. Implications and limitations are discussed.

Research Question 1:

Does Scaffolding Treatment Influence Epistemological Reasoning?

A modified version of the framework developed by Driver et al. (1996) was used to investigate this question. Driver et al. defined epistemological reasoning according to three levels: phenomenon-based reasoning, relation-based reasoning, and model-based reasoning. For the two studies reported here, intermediate levels were added, yielding a five-level scale (see Table 7). Coding of the laboratory reports yielded distributions across levels of reasoning that were remarkably consistent across each of the three scaffolding groups in each study and across the two studies. About 15% of the student explanations demonstrated evidence of relation-based reasoning, less than 5% of the

explanations were an intermediate between relation-based and model-based reasoning, and no explanations attained the level of model-based reasoning as defined by Driver et al. (1996). Statistical tests of the scaffolding effect yielded no evidence that domain-specific or domain-general scaffolds influenced epistemological reasoning.

Model-based reasoning is the gold standard for epistemological reasoning in science; scientists use model-based reasoning to do science (Chinn & Malhotra, 2002). The college student participants primarily used phenomenon-based reasoning, with very few advanced reasoning statements. In both experiments, students most often used phenomenon-based reasoning or relation-based reasoning or the intermediate between phenomenon-based and relation-based reasoning. Results confirm previous reports that students rarely used model-based reasoning (e.g., Chi, Feltovich, & Glaser, 1981; Driver et al., 1996; Hartley, et al., 2011; Stephens et al., 1999; Treagust, Chittleborough, & Mamilia, 2002).

Possible reasons that students failed to use relation-based or model-based reasoning include: (1) students completed the assignment with an answer in order to be assigned a grade; in other words, students were "doing school" rather than doing science (Jiménez -Aleixandre, Rodriquez & Duschl, 2000); (2) students believed the data were self-explanatory, or believed that the instructor recognized the correct answer, making provision of an explanation unnecessary (e.g., Sandoval and Millwood, 2005); and (3) students found the task of integrating multiple conceptual models in a single explanation to be beyond their capabilities as scaffolds are most effective when the task at hand is not beyond a student's capabilities (Stone, 1998).

Despite the availability of both technology-based and paper-based scaffolding tools, as well as written conceptual prompts integrated with laboratory activities, the task may have exceeded students' capabilities for recognizing and using multiple conceptual models necessary in the explanations. Both activities in this research required students to use multiple conceptual models to explain how data are used as evidence.

The first conceptual model was about the methodology for separating DNA pieces by size. Three interacting variables influence the appearance of data patterns generated by the laboratory technique; applied voltage, percent agarose, and run time. The technique involves an applied voltage that pushes on the DNA due to the net negative charge on the DNA molecules. The ratio of negative charge to DNA molecule size is constant; therefore, larger molecules are more affected by the resistance force applied from the gel (a greater per cent agarose imposes a greater resistance force on the DNA molecules). Model-based explanations about the data patterns arising from agarose gel electrophoresis require domain knowledge about charge on the DNA molecules, applied voltage force, and frictional resistance force.

The second conceptual model was about using molecular scissors to cut DNA at specific locations. Depending on the number of explicit cut sites and the distance between the sites, one or more linear pieces are produced from cutting the circular plasmid DNA. Scientists use molecular scissors that recognize explicit cut sites (restriction digest enzymes) on the DNA. After cutting DNA, the DNA is separated by size (first conceptual model).

The third conceptual model was about using a molecular mechanism to amplify desired segments of DNA. Scientists use a technique called PCR to amplify explicit segments of DNA. Next the DNA is separated by size (first conceptual model). Resources about PCR were included in the laboratory manual.

Finally, the fourth conceptual model was about using experimental controls and standards to characterize quality of an experiment for data interpretation. All data patterns in the laboratory activities conducted in this research consist of sets of lines in each column (see Figures 3 and 4). In the molecular biology technique used by students in this research, controls were used to identify whether or not DNA has been cut or amplified and experimental standards were used to estimate the size of the DNA pieces. Resources about experimental controls and standards were included in the lab manual.

Model-based explanations require students to understand and to use appropriate scientific terminology and concepts. The laboratory manual contained extensive, resources about each laboratory activity. Additional resources about physics and chemistry resources that help invoke students' prior knowledge

For example, inclusion of a concept map about how particles behave in an electric field or about how an applied force opposes a frictional force, can help students revisit or recall concepts about force and electric charge in physics and chemistry. Instructors may assume students' previous experience with relevant concepts is sufficient enough to be used without additional resources. In this study, however, discussions about voltage as the applied force and agarose percent as the frictional force of resistance imposed on the negatively charged DNA molecules were not included in

any of the 2,348 coded explanations. Additionally, there was a considerable amount of scientifically appropriate terminology in the laboratory manual (e.g., agarose gel, cell lysis, centrifuge, cloning vector, dye front, restriction digest, endonuclease, etc.), yet the terms were rarely included in explanations (see the discussion for Research Question 3). Graphical representations and/or concept maps might have provided additional instructional scaffolding support within this distributed scaffolding system.

Stephens et al. (1999) found that high school students' epistemological reasoning levels improved when post-lab work included a graphical representation about a model to explain a scientific phenomenon. Stephens used a modified Driver et al. (1996) framework with epistemological reasoning levels for phenomenon-based reasoning, relation-based reasoning, with lower order model-based reasoning and higher order model-based reasoning. The lower model-based reasoning was essentially an intermediate between relation-based reasoning and model-based reasoning. In their study, Stephens et al. observed 12 explanations out of a total 1,000 explanations using higher order model-based reasoning, whereas this research, which used undergraduate participants found the equivalent of 11.5 per 1000 explanations were, essentially, lower order model-based reasoning. Including graphical representations in the distributed scaffold system might have helped students think about theoretical frameworks to include in explanations.

Including concept maps (Novak & Gowan, 1984) or Knowledge maps (O'Donnell, Dansereau, & Hall, 2002) as components of a scaffolding tool for topics being investigated may be useful components a distributed scaffolding system. For

example, conceptual knowledge about experimental parameters, standards, and controls can be graphically represented in a concept map resource for the laboratory manual. Students may have prior knowledge about the topics identified, but may not recognize meaningful patterns associated with deep, non-linear understanding of relevant content knowledge (NRC, 2000), and concept maps can help activate prior knowledge. Additionally, interactive concept maps could be generated for students to use in the course webpage resource.

Model-based reasoning may require multiple science courses to facilitate development of this essential skill (Hartley et al., 2011). In our current system, unfortunately, undergraduates are often exposed to verification-type activities in laboratory science (Windschitl, Thompson, & Braaten, 2008) and are then expected to generate explanations that illustrate model-based reasoning without sufficient support.

Requiring students to use standards and controls in science classrooms may lead students to consider relevant domain knowledge and conceptual models associated with the experimental parameters. When students are prompted to consider the link between a conceptual model and the experimental data, model-based reasoning increases in student explanations (Stephens et al., 1999). Distributed scaffolding systems for model-based reasoning should include prompts that encourage students to consider experimental controls and standards, and how experimental parameters influence observed data patterns for controls and standards. When students are encouraged to carefully consider the outcome patterns of controls and standards, alternative explanations may be considered by the students.

Research Question 2:

Does Epistemological Reasoning Improve with Practice?

The students completed eight laboratory reports during the course of the study, but there was no evidence of improvement for any group in either study. There was, however, an unexpected spike of improvement in reasoning for laboratory question 4. Therefore, this section discusses laboratory question 4, instructional resources, and scaffolds. Example students response for each of the four levels observed in the laboratory reports are provided for purposes of illustration.

Laboratory Question 4 from the Genetics 301/302 Lab Manual

You should notice that the size of uncut plasmid B does not match the size of singly cut plasmid B. This is not an error on your part. Rather, it is due to an intrinsic property of plasmid DNA. Propose an explanation for this discrepancy. (Hint: Think of the factors that determine mobility of a molecule through an agarose gel.) Explain your answer.

Genetics 301/302 Laboratory Manual Excerpt

Although many of you have done electrophoresis in other classes, we are going to briefly review some of the basics. As you probably know agarose gel electrophoresis separates DNA molecules by applying an electric potential across an agarose gel matrix. Since its phosphate backbone gives DNA a strong negative charge, it will move away from the negative terminal and toward the positive terminal. Three factors determine mobility through an agarose gel:

1. Size: small molecules will travel faster than large molecules.

2. Shape: compact shapes will travel faster than open shapes.
3. Agarose concentration: more concentrated agarose will generally resolve smaller fragments.

Phenomenon-Based Reasoning (Level 1.0) Student Response

The shape of the plasmid could cause the discrepancy of the bands.

Intermediate (Level 1.5) Student Response

Due to the shape of the cut DNA, it will not travel in the gel the same distance and won't match size.

Relation-Based Reasoning (Level 2.0) Student Response

The uncut plasmid has a circular shape and the cut plasmid has a linear shape, so we know that compact shapes will move faster than open shapes, therefore, the uncut plasmid will travel slower because it is larger.

Intermediate (Level 2.5) Student Response

A reason for the discrepancy is because the uncut plasmid will still be circular, while the single cut won't. Therefore, it can be compared because the uncut plasmid may look small, but it may be jumbled up to look that way. The smaller DNA fragments moved faster through agarose gel due to the gel's porosity for the same voltage. The cut plasmid will be linear and may therefore seem larger and affect the distance it will travel across the gel.

Scaffolds for Question 4

With each scaffolding treatment, the following excerpt appeared: When answering the questions in your lab report, try to include information provided in lab, in the lab manual, and in your lecture course.

No scaffold. No additional information was provided for students.

Domain-General Scaffold. Completing these sentences may help you think about information to include in your explanations:

Important experimental parameters to consider for data analysis include ____.

An experimental standard is used because ____.

Domain-Specific Scaffold. The DNA fragments separate according to size because ____.

The MW standard is included in the plasmid DNA digestion experiment because__.

When asked to explain a phenomenon, students tend to use available knowledge and resources (Ericsson & Simon, 1980). The scaffolds in this research prompted students to consider relevant domain knowledge available in the laboratory manual, recitation notes, and lecture notes. Students rarely included terminology or conceptual knowledge, other than that information found in the lab manual excerpt referenced in the question 4 hint about factors affecting molecule mobility. Students used the laboratory manual language almost verbatim in their explanations. For example, most students explained that small molecules travel faster than large molecules or that compact shapes move faster than open or linear shapes. The persistent use of relation-based reasoning in

the language of students' explanations indicated that students were "doing school", rather than doing science (Jimenez-Aleixandre, Rodriquez & Duschl, 2000), because the language used in the laboratory manual resource directly influenced learners' responses.

At the beginning of the lab, teaching assistants instructed students to consider the information in the written scaffolds provided at each laboratory station. The additional hint with laboratory question 4, however, was in the lab manual and may have been more difficult to ignore than the written scaffolds provided at students' work stations; imbedding scaffolds directly in the questions, rather than providing scaffolds on separate documents may benefit students.

Research Question 3:

What Are the Relationships among Content Knowledge, Epistemological Beliefs about Scientific Knowledge and Epistemological Reasoning?

Both experiments yielded some statistically significant bivariate correlations. Experiment 1 results indicated the bivariate correlation coefficient was statistically significant for posttest knowledge and epistemological beliefs about scientific knowledge. One study reported a direct relationship between reasoning and posttest knowledge; Lawson and Worsnop (1992) found that student reasoning had a greater influence on knowledge gains than did prior knowledge.

Experiment 2 results indicated a statistically significant relationship was between pretest knowledge and epistemological beliefs about scientific knowledge. Researchers have argued that existing domain knowledge is instrumental for epistemological reasoning (e.g., Duncan, 2007; Hogan & Maglienti, 2004; Lawson, 2005; 2009);

however, reports of bivariate correlations between measured prior knowledge (pretest) and measured epistemological reasoning are noticeably missing from the science education literature.

Research Question 4:

Does Scaffolding Treatment Influence Domain Knowledge Gain?

The pretest knowledge covariate had a statistically significant effect on posttest knowledge scores in both experiments. A main effect from scaffolding was statistically significant for Experiment 1 participants but not for Experiment 2 participants. In this section, a discussion about the influence of scaffolding for Experiment 1 participants by a discussion of additional factors that contributed to knowledge gains for both experiments.

The laboratory teaching assistants used the same PowerPoint presentations and the same recitation notes for each lab section, but there were four lecture professors who taught participants in this study. One lecture professor taught all Experiment 1 participants, and three lecture professors taught Experiment 2 participants. Furthermore, participants in both experiments used the same laboratory manual but the scope and sequence was somewhat different for the Genetics 301 and Genetics 302 courses. For example, molecular genetic mechanisms were covered in Genetics 302, but not in Genetics 301.

In the genetics 301 lecture course, relevant domain concepts were discussed in lecture prior to each laboratory activity; students received extensive domain-specific knowledge. Greater domain-specific knowledge helps explain why there was a

statistically significant main effect for scaffolding treatment on knowledge gains (see ANCOVA results for Research Question 4) by Experiment 1 domain-general treatment group participants because research indicates that students with substantive prior knowledge are more likely to benefit from domain-general scaffolds than from domain-specific scaffolds.

A statistically significant main effect for scaffolding treatment was not observed for participants in Experiment 2. Two factors may have contributed to student knowledge gains; (1) computer-simulated experiments were used prior to the equivalent hands-on experiments and (2) students' epistemological reasoning during completion of the lab reports.

First, knowledge gains are reported for students performing computer-simulated experiments prior to equivalent hands-on experiments. For example, Zacharias and Anderson (2003) found that when college students in an introductory physics class performed computer-simulated experiments prior to equivalent hands-on experiments, content knowledge scores significantly increased as compared to knowledge scores for control group students who had performed only the hands-on experiment. Similar results were reported when elementary school students used computer-simulated electric circuit experiments followed by equivalent hands-on electric circuit experiments (Jaakola & Nurmi, 2007).

Second, epistemological reasoning has previously played a role in students' posttest knowledge gains. Lawson & Worsnop (1992) found high school biology students had a statistically significant direct relationship between posttest declarative

knowledge and pretest reasoning skills after students' had engaged in the instructional module for three weeks and then posttest knowledge was obtained by the researchers.

In this research, a statistically significant relationship between average epistemological reasoning and posttest knowledge scores was identified for participants in Experiment 1 and Experiment 2. Similar results were reported when Lawson & Worsnop (1992) measured reasoning skills using a researcher-generated test prior to the study; students explained answers about graphical representations of scientific phenomena (e.g., concentration away, volume displacement, control of variables). Students conducted laboratory activities and then generated explanations; epistemological reasoning evident in the explanations was consistent throughout the study.

Implications of the Study

The study of instruction designed to enhance students' epistemological reasoning about how data are used as evidence is important because students have difficulty using evidence in evidence-based scientific knowledge claims. Research to this point has investigated how students benefit from scaffolding to support explanation construction that links evidence to a scientific knowledge claim; students primarily use insufficient epistemological reasoning to transform data to evidence, prior to using the data as evidence to support a scientific knowledge claim.

Findings of this research confirm previously reported results about students' limited model-based epistemological reasoning. Limited model-based reasoning has been reported for data obtained from interviews (e.g., Grosslight et al., 1991; Smith &

Wenk, 2006), questionnaires (e.g., Driver et al., 1996; Ryder & Leach, 2000), from computer-assisted science learning environments (e.g., Sandoval & Millwood, 2005; Sandoval & Reiser, 2003), from hybrid hands-on experiments with technology-based scaffolding tools for sense making (e.g., Land & Zembal-Saul, 2003; Clark & Sampson, 2007), and from laboratory activities (Stephens et al., 1999). This research reports a considerable amount of phenomenon-based reasoning with an intermediate between phenomenon-based reasoning and relation-based reasoning and no observed model-based reasoning by college students engaged in laboratory activities in an introductory genetics laboratory classroom.

Additional research is needed to test kinds of scaffolds, scaffolding tools, and instruments to measure student characteristics (e.g., epistemological beliefs about scientific knowledge and prior knowledge) that influence facilitate model-based reasoning in science classrooms. In this study, students almost exclusively used relation-based reasoning when a hint (with laboratory report question 4) helped them locate information in the laboratory manual, but this most likely happened because the language in the lab manual was written in the relation-based reasoning category. How conceptual models are represented in student resources is an important consideration for future instructional design.

The relationships among scaffolding tools, scaffold treatments, pretest knowledge, posttest knowledge, epistemological beliefs about knowledge, and epistemological reasoning are complex and little has been reported about them in the literature. In order to better study these variables, finer grained coding schemes for

students' explanations and greater reliability for instruments is needed. Studies are needed with more reliable measures that can help tease apart the complex relationships of these variables.

Limitations of the Study

Transfer of Results

This research was conducted in the context of the laboratory portion of an introductory college genetics course. Students' scientific reasoning is intimately connected to context (Séré, Fernandez-Gonzalez, Gallegos, Gonzalez-Garcia, De Manuel, Perales, & Leach, 2001) and results of this research may not transfer to other contexts.

Instructional Contribution from Instructors

Teachers play an important role in the learning environment and can influence student learning in classroom environments (Pea, 2004; Tabak & Baumgartner, 2004). Each laboratory section was taught by a different teaching assistant and all teaching assistants used the same PowerPoint presentations, the same laboratory manual sections, and received the same professional development prior to each laboratory activity; however, teaching assistant influences on student performance were not investigated. A better understanding about mechanisms teaching assistants use to engage students may provide useful information about how to support students with distributed scaffolding systems in complex classroom environments.

Epistemological Beliefs about Scientific Knowledge Instrument Score Reliability

Reliability is a property of scores, rather than individuals, and item score variance is highly influenced by the level of group homogeneity represented by the items; greater variance for student responses results in a larger reliability coefficient. Scores from all 26 items on the Nature of Science as Argument Questionnaire (Sampson & Clark, 2006) had poor reliability; Cronbach's alpha was .526 for participants' scores in Experiment 1, and .659 for participant scores in Experiment 2. After scores from items 3, 9, and 10 were systematically dropped from the questionnaire, reliability improved to $\alpha = 0.61$ for Experiment 1 participant scores and $\alpha = 0.71$ for Experiment 2 participant scores. While a value of .70 is acceptable (Cronbach, 1951), it is low and should be considered with caution.

Small values for alpha indicate response homogeneity and, therefore, lower variance among students. Lower variance for item responses means that scores are not likely to represent student differences in epistemological beliefs about scientific knowledge. For example, if participants uniformly select a less sophisticated statement over a more sophisticated statement (e.g., scientific knowledge is objective compared to scientific knowledge is subjective) then items are less likely to contribute to our understanding of how epistemological beliefs about scientific knowledge influence epistemological reasoning.

Limited Range of Epistemological Reasoning

Although there were five categories for epistemological reasoning, model-based reasoning was not observed and the intermediate between relation-based and model-

based reasoning was only rarely observed in student explanations. Furthermore, the Yates correction reduced the epistemological reasoning categories from four to three, further limiting variability in the outcome measure for all three scaffolding treatments. Limited variability also limits the usefulness of conclusions about the effectiveness of scaffolding treatment.

Future Research

Greater understanding about how prior knowledge and epistemological beliefs about the nature of scientific knowledge influence epistemological reasoning for college students is warranted. In order to understand the relationship among the variables, however, additional research about measurement instruments with greater reliability is needed to interpret the results from kinds of scaffolding tools for model-based reasoning in college science courses.

A key criticism for written scaffolds is that static, written prompts are often less effective than adaptive prompts provided by more knowledgeable others (Azevedo, Cromley, Winter, Moos, & Greene, 2005; Pea, 1985; 2004; Puntambekar & Hubscher, 2005; Stone, 1998; Wood & Brunner, 1976). Dynamic, adaptive scaffolds can be delivered by peers (King, 1991), teachers (Azevedo, Cromley, Winters, Moos & Greene, 2005; Tabak & Baumgartner, 2004), or both peers and teachers (Palincsar & Brown, 1984; Puntambekar & Kolodner, 2005). Research is needed about the effectiveness of hard and soft scaffolds in distributed scaffolding systems; using both hard and soft scaffolds may better facilitate model-based reasoning

While the epistemological reasoning coding framework developed by Driver et al. (1996) provided a reasonable framework for students' epistemological reasoning in this study, the limited number of categories for epistemological reasoning posed a considerable limitation for data analysis. The number of epistemological reasoning categories may be increased if thematic categories are developed from students' explanations. Additionally, observing college students performing laboratory activities, as well as conducting individual interviews and conducting focus groups can provide additional insight about students' conceptual understandings and misunderstandings about scientific data and evidence.

If the modified Driver et al. (1996) framework is used in future research studies, additional student variables need to be examined. For example, learning more about how students use computer-simulated experiments as a scaffolding tool to visualize data (Chinn & Malhotra, 2002; Gordin & Pea, 1995; Hofstein & Lunetta, 2004), manipulate experimental variables and observe how data patterns change (Chinn & Malhotra, 2002) and to use virtual equipment much like that used by scientists.

Programming virtual laboratory environment software to collect information about students' pathways through the computer-simulated experiments can provide rich data sets about students' laboratory practices. For example, examining how students explore the influence of variables on data patterns can help identify successful student strategies and lead to improved scaffolds development. The role technology plays in epistemological reasoning about data and evidence has not been fully explored and additional research is warranted.

How students use and learn domain knowledge is another area for future research about epistemological reasoning. Reiser et al. (2001) argued that instructional support about science processes cannot be resolved by simply using either domain-general or domain-specific supports, but rather, by exploring how design strategies influence student performance and compare tradeoffs of the various design strategies. At the same time, however, I believe students' use of domain knowledge types will help in scaffolds design. For example, should domain-specific and domain-general scaffolds be delivered as hard scaffolds or as soft scaffolds?

If students are to become more critical scientific data evaluators, the role of experimental controls and standards should become explicitly taught throughout each science course. Data interpretation is subjective; students must become proficient at learning how to think about data and evidence using conceptual models. Scientists use controls to judge the quality of the data as evidence, but students often do not even consider issues associated with the use of controls to qualify data. Unfortunately, students often blindly follow cookbook procedures and directions without considering the need for controls or standards. If science courses require students to explicitly learn about both domain-general and domain-specific issues associated with experimental controls and experimental standards, repetitive practice can institute the use of controls and standards to justify and explain how data are used as evidence. As a consequence, students may begin to question the validity of using data as evidence, and students may begin to question the validity of simple verification experiments.

This research has raised a number of questions yet to be examined by researchers, especially at the college level. College students in this research performed model-based reasoning in a similar fashion to middle school and high school students. In order to sustain a knowledgeable scientific community, as well to develop as a scientifically literate population, the challenge is painfully obvious; model-based reasoning needs to be explicitly characterized in evidence-supported scientific knowledge claims. Exploring ways to develop this level of epistemological reasoning in college students should result in a greater number of scientifically literate graduates.

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APPENDIX A

PRIOR KNOWLEDGE QUIZ

1. Agarose gels are porous solid materials used as molecular sieves to separate molecules like DNA. The distance that a piece of DNA travels through an agarose gel can be predicted from (select all that apply):
 - A. the size of the DNA
 - B. the shape of the DNA
 - C. the sequence of the DNA
 - D. the kinds of chemical bases in the DNA

2. *Which of these gels should be used to provide the best separation of very small DNA fragments?*
 - A. 0.5% agarose gel
 - B. 1.0% agarose gel
 - C. 1.5% agarose gel
 - D. 2.0% agarose gel

3. Which of these factors provides the force that pushes DNA through a gel?
 - A. Time
 - B. % Agarose
 - C. Voltage
 - D. Current

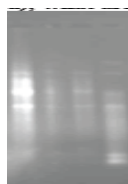
4. Two gels have been loaded with exactly the same DNA. The first gel is run at 50 volts and the second gel is run at 100 volts. The DNA bands on the gel run at 50 volts are _____ compared to the bands on the gel run at 100 volts.
 - A. closer together
 - B. farther apart
 - C. the same distance apart
 - D. running off the gel

5. DNA has a strong negative charge. This means that DNA will move from the ____ pole to the ____ pole.

- A. north
- B. south
- C. negative
- D. positive

6. Which of these electrophoresis factors is most likely responsible for smeared DNA bands?

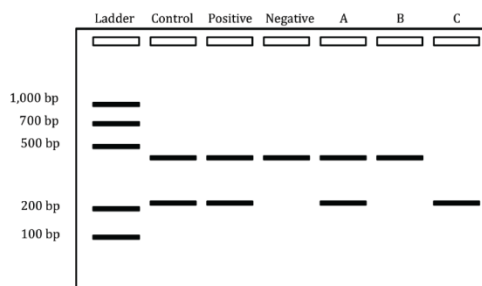
- A. Voltage set too high
- B. Run time too long
- C. % agarose too large
- D. none of these factors



7. In Polymerase Chain Reaction (PCR) experiments, scientists amplify genes of interest and then visualize the results using agarose gel electrophoresis. Which of these factors is essential for amplifying specific genes?

- A. using the molecular ladder to identify the gene
- B. using a positive control for the gene
- C. using a negative control for the gene
- D. using specific primers for the gene

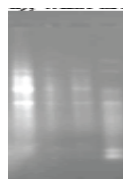
8. The plant gene is about 550 bp and the Bt insert is about 200 bp. On the gel picture below, which lane(s) has/have DNA that has been genetically modified (identify all that apply)?



- A. A
- B. B
- C. C
- D. Ladder

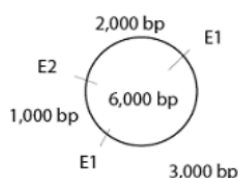
9. Which of these experimental factors is most likely explains why DNA smears appear on a gel?

- A. a positive control was used
- B. enzyme was used to cut the DNA
- C. denatured DNA was present
- D. a negative control was used



10. How many DNA bands should be visible on an agarose gel if the following circular DNA is successfully cut at all sites for E1 and E2?

- A. One
- B. Two
- C. Three
- D. Four



11. There are several versions of the Bt gene. One version is believed to cause an allergic reaction in humans and it should not be used in food plants, like corn. The best way to be certain which form of the Bt gene is present in a sample is when ____.

- A. the sample matches the negative control
- B. the sample matches the positive control
- C. the sample sequence is known
- D. the sample matches other samples

12. Polymerase Chain Reaction (PCR) is a process that amplifies desired DNA fragments. PCR mimics ____.

- A. translation
- B. transcription
- C. replication prior to mitosis
- D. mutagenesis

APPENDIX B

THE NATURE OF SCIENCE AS ARGUMENT QUESTIONNAIRE

Directions: Read the following pairs of statements and then circle the number on the continuum that best describes your position on the issue described. The numbers on the continuum mean:

1 = I complete agree with viewpoint A and I completely disagree with viewpoint B.

2 = I agree with both viewpoints but I agree with viewpoint A more than I agree with the viewpoint B

3 = I agree with both viewpoints equally.

4 = I agree with both viewpoints but I agree with viewpoint B more than I agree with viewpoint A

5 = I completely agree with viewpoint B and I completely disagree with viewpoint A

What is the nature of scientific knowledge?

	Viewpoint A	A not B	A > B	A = B	A < B	B not A	Viewpoint B
1	Scientific knowledge describes what reality is really like and how it actually works.	1	2	3	4	5	Scientific knowledge represents only one possible explanation or description of reality
2	Scientific knowledge should be considered tentative	1	2	3	4	5	Scientific knowledge should be considered certain.
3	Scientific knowledge is subjective	1	2	3	4	5	Scientific knowledge is objective
4	Scientific knowledge does not change over time once it has been discovered.	1	2	3	4	5	Scientific knowledge usually changes over time as the result of new research and perspectives.
5	The concept of 'species' was invented by scientists as a way to describe life on earth.	1	2	3	4	5	The concept of 'species' is an inherent characteristic of life on earth, it is completely independent of how scientists think

6	Scientific knowledge is best described as being a collection of facts about the world.	1	2	3	4	5	Scientific knowledge is best described as an attempt to describe and explain how the world works.
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How is scientific knowledge generated?

	Viewpoint A	A not B	A > B	A = B	A < B	B not A	Viewpoint B
7	Experiments are important in science because they can be used to generate reliable evidence.	1	2	3	4	5	Experiments are important in science because they prove ideas right or wrong.
8	All science is based on a single -scientific method.	1	2	3	4	5	The methods used by scientists vary based on the purpose of the research and the discipline.
9	The methods used to generate scientific knowledge are based on a set of techniques rather than a set of values.	1	2	3	4	5	The methods used to generate scientific knowledge are based on a set of values rather than a set of techniques.
10	Experiments are important in science because they can be used to generate reliable evidence.	1	2	3	4	5	Experiments are important in science because they prove ideas right or wrong.
11	An experiment is used to test an idea.	1	2	3	4	5	An experiment is used to make a new discovery.

12	Within the scientific community, debates and discussions that focus on the context processes, and products of inquiry are common.	1	2	3	4	5	Within the scientific community, debates and discussions that focus on the context processes, and products of inquiry are rare.
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What counts as reliable and valid scientific knowledge?

	Viewpoint A	A not B	A > B	A = B	A < B	B not A	Viewpoint B
13	Scientific knowledge can only be considered trustworthy if the methods, data, and interpretations of the study have been shared and critiqued.	1	2	3	4	5	Scientific knowledge can be considered trustworthy if it is well supported by evidence.
14	The scientific method can provide absolute proof.	1	2	3	4	5	It is impossible to gather enough evidence to prove something true.
15	If data was gathered during an experiment it can be considered reliable and trustworthy.	1	2	3	4	5	The reliability and trustworthiness of data should always be questioned.
16	Scientists know that atoms exist because they have made observations that can only be explained by the existence of such particles.	1	2	3	4	5	Scientists know that atoms exist because they have seen them using high-tech instruments.

17	Biases and errors are unavoidable during a scientific investigation.	1	2	3	4	5	When scientific investigation is done correctly errors and biases are eliminated.
18	As theory should be considered inaccurate if a single fact exists that contradicts that theory.	1	2	3	4	5	A theory can still be useful even if one or more facts contradict that theory.
19	Scientists can be sure that a chemical causes cancer if they discover that people who have worked with that chemical develop cancer more often than people who have never worked with that chemical.	1	2	3	4	5	Scientists can only assume that a chemical causes cancer if they discover that people who have worked with that chemical develop cancer more often than people who have never worked with that chemical.

What role do scientists play in the generation of scientific knowledge?

	Viewpoint A	A not B	A > B	A = B	A < B	B not A	Viewpoint B
20	In order to interpret the data they gather scientists rely on their prior knowledge, logic, and creativity.	1	2	3	4	5	In order to interpret the data they gather, scientists rely on logic only and avoid using their creativity or prior knowledge.
21	Scientists are influenced by social factors, their personal beliefs, and past research.	1	2	3	4	5	Scientists are objective, social factors and their personal beliefs do not influence their work.

22	Successful scientists are able to use the scientific method better than unsuccessful scientists.	1	2	3	4	5	Successful scientists are able to persuade other members of the scientific community better than unsuccessful scientists.
23	Two scientists (with the same expertise) reviewing the same data will reach the same conclusions.	1	2	3	4	5	Two scientists (with the same expertise) reviewing the same data will reach different conclusions.
24	A scientist's personal beliefs and training influences what they believe counts as evidence.	1	2	3	4	5	What counts as evidence is the same for all scientists.
25	The observations made by two different scientists about the same phenomenon will be the same.	1	2	3	4	5	The observations made by two different scientists about the same phenomenon can be different.
26	It is safe to assume that a scientist's conclusions are accurate because they are an expert in their field.	1	2	3	4	5	A scientist's conclusions can be wrong even though scientists are experts in their field.

APPENDIX C

IRB APPROVED STUDENT INFORMED CONSENT

CONSENT FORM

The Influence of Scaffolding Treatment on Students' Evidence Explanations

Introduction

The purpose of this form is to provide you information that may affect your decision as to whether or not to participate in this research study. If you decide to participate in this study, this form will also be used to record your consent.

You have been asked to participate in a research project studying the influence of scaffolding conditions on scientific explanations. The purpose of this study is to explore the kinds of learner supports that facilitate students' evidence explanations in genetics labs. You were selected to be a possible participant because you are enrolled in Gene 301 or Gene 302 at Texas A&M University.

What will I be asked to do?

If you agree to participate in this study, you will be asked to complete two different survey questionnaires. This study will take place over three laboratory periods. In the first lab period, you will be asked to complete two surveys; one about your genetics laboratory concepts knowledge, and one about your beliefs about the nature of science.

You will conduct computer simulated experiments and hands-on experiments and then analyze the data and submit a laboratory report. Data for this study will include the two surveys completed during the first lab period and your laboratory reports for the following laboratory experiments: Standard Curves (generating standard curves from computer-simulated experimental data), Restriction Enzyme Analysis of Plasmid DNA (enzyme digestion results), and the GMO Experiment (both the hands-on PCR lab and the virtual PCR lab for the Bt gene in corn). These laboratory experiments are in the Genetics 301 and Genetics 302 lab manuals. You will conduct all experiments and submit laboratory reports for a grade whether you participate in this study or not.

What are the risks involved in this study?

The risks associated in this study are minimal, and are not greater than risks ordinarily encountered in daily life.

What are the possible benefits of this study?

The possible benefits of participation are that you will learn more about how data becomes evidence in science. Additionally, the results of this study may impact the design of future laboratory activities and resources to be used in subsequent offerings of this course and science instruction in general.

Do I have to participate?

No. Your participation is voluntary. You may decide not to participate or to withdraw at any time without your current or future relations with Texas A&M University or the Genetics Department being affected.

Will I be compensated?

The activities in this study are all part of the scheduled Genetics Laboratory curriculum. You will complete all laboratory activities for a grade whether or not you agree to participate in the study.

Who will know about my participation in this research study?

This study is confidential and all records will be kept in a locked filing cabinet in Christina Shimek's office.

The records of this study will be kept private. No identifiers linking you to this study will be included in any sort of report that might be published. Research records will be stored securely and only Christina Shimek, Ernest T. Goetz, or Cathleen C. Loving will have access to the records.

Whom do I contact with questions about the research?

If you have questions regarding this study, you may contact Christina Shimek, 979-845-3049, or christines@tamu.edu.

Whom do I contact about my rights as a research participant?

This research study has been reviewed by the Human Subjects' Protection Program and/or the Institutional Review Board at Texas A&M University. For research-related problems or questions regarding your rights as a research participant, you can contact these offices at (979)458-4067 or irb@tamu.edu.

Signature

Please be sure you have read the above information, asked questions and received answers to your satisfaction. You will be given a copy of the consent form for your records. By signing this document, you consent to participate in this study.

Signature of Participant: _____ **Date:** _____

Printed Name: _____

Signature of Person Obtaining Consent: _____ **Date:** _____

Printed Name: _____

VITA

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